

A TEXT BOOK
OF
PRACTICAL PHYSICS

For B. Sc. (MAIN) STUDENTS

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INDIA

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For B.Sc. (MAIN) STUDENTS

Rama. Arumuchalam

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FOREWORD

BY

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The beneficent influence that laboratory work exercises on the understanding of scientific subjects cannot be over-emphasized. It is, therefore, the duty of physics teachers to ensure that a sound laboratory training is given to their students. Practical work, it need hardly be added, improves the powers of observation and enhances manipulative skill.

While it is true that no book can possibly replace the teacher, the student must learn not to be completely dependent on him. It is necessary that the pupil should go to the laboratory thoroughly prepared for the prescribed exercise, so that he may be in a position to fully assimilate the teacher's instruction. Good books are, therefore, absolutely essential to supplement the efforts of teachers.

Professor A. G. Narasimham is well qualified to write a book on B.Sc. Practical Physics. He has to his credit nearly three and a half decades of service as a teacher. He has taught all classes from the Intermediate to the Honours Standard. He is thus in a position to judge correctly the requirements of B.Sc. students.

The book is expected to meet the needs of the B.Sc. (Main) students. The experiments are presented neatly and concisely. Detailed instructions are given at those places where the average student is likely to find some difficulty and apparent points are not dealt with at undue length.

I ardently hope that students will make excellent use of the book and greatly improve the quality and quantity of their practical work.

SRI VENKATESWARA UNIVERSITY, TIRUPATI, July 14, 1957. •	} S. RAMACHANDRA RAO, Professor of Physics.
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PREFACE

The main object in bringing out this book is to make available to the student of the B.Sc. degree course, more or less *complete instructions* for the performance of experiments in Practical Physics. They are not, however, intended to replace *entirely, personal instructions* from experienced and skilled professors and demonstrators. No text-book, however thorough it might be, can be a substitute for a good teacher. A few timely hints and occasional help in the adjustment of precision instruments and in the taking of readings correctly, are of far greater value, than pages of written instructions. But, due to the large and increasing number of students working simultaneously in laboratories nowadays, it is commonly observed that the student has to wait for oral instructions, *even for starting* the experiment and that he does not spend *all the time* allotted for practical work, for the performance of the experiment. It is fondly hoped that the detailed instructions given in this book will help the average student *to utilise the whole of the time set apart for practical work*, without wasting any part of it in waiting for oral instructions. Experimental skill comes with constant practice and it is essential for the student to spend as much time as possible, for the performance of experiments in the laboratory in a thorough and systematic manner.

In many of the experiments, brief explanations of the theoretical principles involved in them have been given. Suitable tabular forms for entering the results have been included, wherever necessary. Numerical results have been given in many experiments to serve as examples. They have been taken from the experiments performed by B.A. and B.Sc. students. It is expected that they will serve to guide the average student. Some of them can certainly be improved upon, as regards accuracy, by good students.

The book is divided into two parts. In the first part, after a brief Introduction, there are four Sections, dealing respectively with Preliminary experiments, General Physics (Properties of Matter), Heat and Sound, with forty-eight experiments in all. In

the second part there are three Sections dealing respectively with Light, Magnetism and Electricity, with fifty-seven experiments in all. Many of the experiments are really compound experiments, requiring two or sometimes three practical work days. They are classified as single experiments, because of the common physical principles involved.

The student is expected to work carefully and thoroughly through the exercises, attaching great importance to *neat, systematic and accurate* work. He must record them properly and carefully. Every experiment must be repeated till satisfactory results are obtained.

The apparatus described for the various experiments are those in common use in most laboratories.

In the experiments with the optic bench, in Light, the *parallax method* of locating the images has been advocated and described, in preference to an illuminated object and an image screen. The parallax method is *simple and accurate*, though it involves greater strain for the eye. But it is hoped that, in view of its special advantages, the student will not mind the trouble involved.

In the formulæ for spherical mirrors and lenses, the sign convention used is that "*distances of real images are positive.*"

Though Sri A. Ramamurthy, one of the authors is an Assistant Professor of Physics in Presidency College, Madras, it is emphasised that this book is neither an official publication nor officially sponsored.

Suggestions for improvement of matter and of the method of treatment are quite welcome.

MADRAS
24th July 1957.

A. G. NARASIMHAM.
A. RAMAMURTHY.
R. RAMAN.

CONTENTS

PAGE

INTRODUCTION

ix

Section I—Preliminary

Experiment

✓ 1.	✓ Vernier Calipers and Screw Gauge	...	...	1
✓ 2.	✓ Spherometer	...	...	6
3.	Optic Lever	...	...	11
✓ 4.	✓ Balance	...	...	15
5.	Vernier Microscope	...	...	20
✓ 6.	✓ Forces at a Point	...	...	24
✓ 7.	✓ Parallel Forces	...	...	27
✓ 8.	✓ Inclined Plane	...	...	32
✓ 9.	✓ Specific Gravities of Solids and Liquids	...	...	35
✓ 10.	✓ Specific Gravity Bottle	...	...	38
✓ 11.	✓ Hydrometers	...	...	41
✓ 12.	✓ Fortins Barometer—Boyle's Law	...	...	44

Section II—General Physics

✓ 13.	✓ Surface Tension by Drops	...	...	49
✓ 14.	✓ Surface Tension of a Liquid by Capillary Rise	...	...	53
✓ 15.	✓ Surface Tension of a Liquid by Searle's Torsion Balance	...	...	56
✓ 16.	✓ Surface Tension of a Liquid by Quincke's Drop Method	...	...	59
✓ 17.	✓ Coefficient of Viscosity of a Liquid by Poiseuille's Flow	...	...	60
✓ 18.	✓ Comparison of the Viscosities of Two Liquids	...	...	64
19.	Borda Pendulum	...	...	67
+ ✓ 20.	✓ Compound Pendulum	...	...	69
✓ 21.	✓ Kater's Pendulum	...	...	72
✓ 22.	✓ Bifilar Pendulum	...	...	78

Experiment

PAGE

23. Young's Modulus by Stretching—

(A) Searle's Apparatus with Micrometer Screw
and Spirit Level ... 80

(B) Searle's Apparatus with Optic Lever, Teles-
cope and Scale ... 84

24. Young's Modulus by Bending—Cantilever ... 86

25. Young's Modulus by Bending—Non-uniform—

(A) Pin and Microscope Method ... 89

(B) Optic Lever Method ... 93

26. Young's Modulus by Bending—Uniform—

(A) Pin and Microscope Method ... 95

(B) Optic Lever Method ... 98

27. Rigidity Modulus by Static Torsion—

(A) Scale and Pointer Method ... 100

(B) Telescope and Scale Method ... 104

28. Rigidity Modulus by Torsional Oscillations ... 106

29. Moment of Inertia by Torsional Oscillations ... 109

30. q , n , and σ by Searle's Method ... 112

Section III—Heat

31. Coefficient of Linear Expansion of a Solid ... 115

32. Coefficient of Apparent Expansion of a Liquid ... 117

33. Coefficient of Increase of Pressure of Air at
Constant Volume—Constant Volume Air
Thermometer ... 12134. Coefficient of Expansion of Air at Constant
Pressure—Constant Pressure Air Thermometer. 125

35. Specific Heats of Solids and Liquids ... 128

36. Latent Heat of Fusion of Ice—Specific Heat of
Liquid using Ice ... 13637. Latent Heat of Steam—Specific Heat of Liquid
using Steam ... 140

Experi- ment	PAGE
38. Melting Point of a Solid (Cooling Curve) and Boiling Point of a Liquid	144
39. Newton's Law of Cooling—Specific Heat of a Liquid	147
40. Thermal Conductivity of Copper — Searle's Apparatus	153
41. Thermal Conductivity of a Bad Conductor—Lee's Disc Method	156
42. Mechanical Equivalent of Heat	159
Section IV—Sound	
43. Resonance	162
44. Volume Resonator	167
45. Frequency of a Tuning Fork—Falling Plate Method	168
46. Kundts Tube	171
47. Sonometer—Laws of Transverse Vibrations of Strings—Frequency of Tuning Fork	174
48. Melde's Apparatus	178
Section V—Light	
49. Photometers	185
50. Refractive Indices of Solids and Liquids—Direct Refraction	189
51. Refractive Indices of Solids and Liquids—Critical Angle Method	195
52. Focal Lengths of Concave and Convex Mirrors ...	198
53. Focal Lengths of Convex and Concave Lenses ...	204
54. Refractive Indices of Convex and Concave Lenses.	214
55. Refractive Indices—Liquid Lens	218
56. Magnifying Powers of Microscopes and Telescopes	222
57. Resolving Power of a Telescope... ..	228

Experiment	PAGE
58. Spectrometer—Angle of Prism and Minimum Deviation	230
59. Spectrometer—Refractive Index of Liquid—Hollow Prism	238
60. Spectrometer—($i - d$) Curve	241
61. Spectrometer—($i_1 - i_2$) Curve and Stokes Formula.	246
62. Spectrometer—Small-angled Prism	250
63. Spectrometer—Total Reflection—Refractive index.	255
64. Spectrometer—Solar Spectrum—Dispersive Power of prism	257
65. Newton's Rings	260
66. Fresnel's Biprism	265
67. Spectrometer—Diffraction grating	270
68. Spectrometer—Fraunhofer's lines—Wave lengths.	276
69. Polarimeter	278

Section VI—Magnetism

70. Deflection Magnetometer—Comparison of Magnetic Moments	280
71. Deflection Magnetometer—Determination of M and H	290
72. Deflection Magnetometer—Pole Strength of Magnet and Verification of Inverse Square Law.	296
(A) Long Magnet	297
(B) Short Magnet	299
73. Vibration Magnetometer	302
74. Mirror Magnetometer—Verification of Inverse Square Law	307

Section VII—Electricity

Electrical Accessories	313
75. Tangent Galvanometer—Calibration of Ammeter.	324

Experi-
ment

PAGE

✓ 76.	Field Along the Axis of a Coil Carrying Current— Deflection Magnetometer	327
77.	Field Along the Axis of a Coil Carrying Current— Vibration Magnetometer	331
✓ 78.	Electro-Chemical Equivalent of Copper	335
79.	Metre Bridge—Specific Resistance	338
✓ 80.	Post Office Box—Specific Resistance	341
✓ 81.	Carey Foster Bridge	345
82.	Temperature Coefficient of Resistance	348
✓ 83.	Mechanical Equivalent of Heat—Electrical Method	351
✓ 84.	Potentiometer—Comparison of E.M.F.'s of Cells and Determination of Internal Resistances of Cells	354
✓ 85.	Potentiometer—Comparison of Resistances	360
86.	Potentiometer— (A) Measurement of Current and Reduction Factor of Tangent Galvanometer	362
✓ (B)	Calibration of Ammeter	365
(C)	Reduction Factor of Tangent Galvano- meter (Alternative Method)	367
✓ 87.	Rayleigh's Potentiometer	369
✓ 88.	Potentiometer—Calibration of Voltmeter (A) Low Range Voltmeter	371
(B)	High Range Voltmeter	372
✓ 89.	Potentiometer—E.M.F. of Thermo-couple	374
✓ 90.	Mirror Galvanometer—Resistance and Figure of Merit	379
✓ 91.	Mirror Galvanometer—E.M.F. of Thermo-couple by Direct Deflection	383

Experi- ment	PAGE
92. Mirror Galvanometer—Comparison of Resistances	
(A) Low Resistances	385
(B) High Resistances	387
93. Ballistic Galvanometer—Comparison of capacities and E.M.F.s	389
94. Ballistic Galvanometer—Absolute Capacity of a Condenser	393
95. Ballistic Galvanometer—Comparison of Mutual Inductances	397
96. Ballistic Galvanometer—Absolute Coefficient of Mutual Induction	399
97. Ballistic Galvanometer—Internal Resistances of Cells	403
98. Ballistic Galvanometer—Reduction Factor of Tangent Galvanometer	405
99. Ballistic Galvanometer—Determination of Con- stant	408
100. Earth Inductor	415
101. Search coil—Pole Strength of a Magnet	419
102. Coefficient of Self Induction—Anderson's Method.	423
103. Conductivity of Electrolytes—Kohlrausch's Method	424
104. Hysteresis—Magnetometer Method	427
105. Characteristics of a Triode Valve... ..	432

APPENDIX I

Questions for Practical Examinations	439
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APPENDIX II

Physical Tables and Constants... ..	449
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TEXT BOOK OF PRACTICAL PHYSICS

INTRODUCTION

General :—Physics has been rightly described as the *Science of precise and accurate measurement*. Hence, the main objects in undergoing training in Practical Physics must naturally be (1) to get familiar with the principles and methods of accurate measurement and (2) to acquire dexterity and skill in performing experiments with ease and elegance. It is possible to achieve this, *only* if there is a clear realisation of the aim of each experiment and a thorough knowledge of the procedure to be adopted. The essential features of construction and the manipulation of the apparatus and instruments that are used for an experiment must be carefully studied. They must be arranged on the work-table neatly and in such a manner that they are within easy reach and can be manipulated and observations taken, with minimum physical discomfort.

Many delicate apparatus and precision instruments will have to be used for performing experiments. Great care and a certain degree of gentleness and sympathy are needed in handling them. Many of them are intended for long and indefinite use. Serious and irretrievable damage may be caused to them, by careless and rough treatment. The Screw-Gauge, the Balance, the Travelling Microscope, the Spectrometer, the Galvanometer, Standard Resistances, etc., require particular care and consideration in use.

Observation note-book :—All the observations made during the course of an experiment must be neatly and systematically noted down in a note-book maintained specially for the purpose. There must be no such thing as making a mental deduction and writing down the result alone. All the observations leading to it must be written down in such a manner that any one can follow them, without the need for a personal explanation from the person performing the experiment. Sufficient explanations must precede or follow each reading or set of readings taken. If more readings than one are taken for a particular observation, they must be entered neatly in a suitable tabular form.

Rejection of observations :—*All* the readings taken must find a place in the observation note-book. *No* reading must be rejected unless it is known for certain that there was a serious flaw in taking it. *No* attempt must be made to alter a reading, under the mistaken impression that it is likely to lead to a wrong result. Getting accurate results comes with experience. Careful manipulation and systematic observation are bound to yield satisfactory results. *An inaccurate result is far less serious than a dishonest attempt to tamper with the readings taken.* It must be well realised that Science has reached its pre-eminent position at the present day as the result of the honest recording of observations by Scientists. Discrepancies in results have often led to the rejection of imperfect laws and formulation of new theories.

Errors in observation:—Watchfulness and alertness are required, if the observations should be faithful and correct. There is likely to be a personal error, to a greater or less extent, in every reading that is taken—in noting a length or a time of transit or a coincidence or a deflection. But alertness will considerably reduce this personal error. *Slovenliness in observation is Public Enemy No. 1, in the performance of an Experiment in Science.*

The larger the quantity used for measurement, the less will be the percentage error. So, consistent with the conditions in the experiment, as large a quantity as possible must be taken. Thus, for determining the radius of a capillary tube with a mercury thread, a long thread of mercury must be used. For determining the specific heat of a solid by the method of mixtures, a fairly large quantity of the solid must be taken. In finding the period of oscillation of a pendulum, the time for as large a number of oscillations as possible must be observed.

Repetition of experiment :—Again, a single reading will never suffice for the measurement of a quantity. The conditions obtaining at the time of measurement must be altered and the experiment repeated. Several readings must be taken, the number of such readings to be taken in any particular measurement, to be decided by the time factor. The average of the readings taken must be

used for calculating the result. It will be nearer the correct reading than any one of them.

It may happen at times that, when a large number of readings are taken, one or more of them differ widely from the rest. This may be due to errors of observation or to an imperfect instrument used or to the nature of the quantity measured, as in the case of the diameter of a wire. There is a general tendency to strike off such inconsistent results. Unless it is known that a definite factor operated which militated against a consistent reading from being taken, it must not be struck off. However, such readings may be left out when the average is taken, since their counterparts are evidently missing.

Estimation :—In very many observations, readings have to be taken with graduated scales. Where a reading coincides with a scale division, there is no difficulty. If, however, it lies between two divisions, the fraction of the division has to be estimated. This requires judgment and correct judgment comes with experience. But, even if the estimate is not very accurate, it will give a better result, than if no attempt is made at estimating it.

Parallax :—Again, in taking a reading involving coincidence, observations must be made from such a position that parallax error is avoided. Thus, when a scale is placed on an object to measure a length, the eye must be *vertically* above the coinciding division. In reading the level of the mercury in the barometer, the eye must be in the same *horizontal* line as the mercury level.

Calculations :—All the details of calculation must be clearly written in the observation note-book itself. This will be particularly helpful in easily tracing any mistake in the calculations that may have crept in.

Significant figures :—In the calculation of an experimental result, a number of different quantities are involved. In determining these quantities, the degree of accuracy possible is different for different quantities. The accuracy of the final result is decided by the least accurate of the quantities measured. So, for the final calculation, only the necessary significant figures must be retained in each quantity. Otherwise, there will be waste of labour and

energy in doing unwanted calculations. Judgment and discretion are necessary for rejecting unnecessary figures in a quantity. Thus, in finding the resting point of a balance, the mean of the left and right turning points may be 9.125. It will be meaningless to use it as such. It must be corrected to the first decimal place and written as 9.1. Any doubt regarding the number of significant figures to be retained for calculation may be cleared by consulting your Professor. With experience, the ability to arrive at the correct decision will be acquired. In the calculated result also, the unnecessary figures must be struck off. The final result must unmistakably indicate the accuracy possible in the experiment.

Graph :—A graph is very useful for revealing the relation between two inter-dependent variable quantities in an experiment. It is often used for determining an unknown quantity. In addition, it shows clearly the divergence of the readings taken, from the ideal readings. So, whenever a number of readings are taken of such quantities in an experiment, they must be represented by a graph. The independent variable *i.e.*, the quantity changed by the experimenter, is represented on the X axis and the dependent variable on the Y axis. The scales must be suitably chosen and the whole of the graph sheet must be used. The origin may represent zero or a quantity slightly less than the minimum measured. The points plotted must be carefully marked and neatly enclosed in small circles. The graph may be a straight line or a smooth curve, dependent on the relation between the quantities. Where there is a definite algebraic relationship between them, the graph is generally a regular geometric figure, such as a straight line, a parabola, a hyperbola etc. It must be realised that it is not necessary that the straight line or curve must pass through all the points plotted. Due to errors of observation, some of the points may not lie on the graph drawn. In such cases, the graph must be drawn in such a manner that as many points lie symmetrically on one side of it as on the other. The points which lie away from the graph indicate the inaccuracies in observation.

Units :—All the quantities measured in experiments in Physics have definite units. So, the units in which they are measured must

invariably accompany the quantities at every stage. Otherwise, the final calculations might give a wrong result. When writing down the final result also, state its appropriate units, unless it happens to be a mere number due to its being a ratio between two quantities of the same kind.

Record :—All the experiments performed during a practical course must be regularly and neatly recorded in a comprehensive manner in a fair record. In writing a fair record, the following points must be kept in view.

The date on which the experiment was performed and the title of the experiment must be written at the top. The aim of the experiment and the apparatus and instruments used in the experiment, must then be mentioned. Brief and intelligible descriptions of the main apparatus must be given. Wherever possible, neat diagrams and sketches of the apparatus must be drawn. The procedure adopted must be explained clearly and the precautions observed in the performance of the experiment, mentioned at the appropriate places. The theory of the experiment, may be indicated briefly, as this is likely to be very useful for reference at a later stage. The readings taken must be entered neatly in suitable tabular forms. Wherever possible, a graph must be drawn. The final result must be clearly written down in bold letters.

Particular care and attention must be devoted to the writing of the fair record. A well maintained record is a valuable asset and a source of pride to its owner.

The following text-books of Practical Physics may be used for reference, whenever doubts arise :—

1. T. G. Bedford—Practical Physics.
 2. Schuster and Lees—Exercises in Practical Physics.
 3. W. Watson—A Text book of Practical Physics.
 4. Worsnop and Flint—Advanced Practical Physics for Students.
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SECTION I

PRELIMINARY

EXPERIMENT I

VERNIER CALIPERS AND SCREW GAUGE

Aim :—To measure accurately small lengths using the Vernier Calipers and the Screw Gauge.

Apparatus required :—Vernier Calipers, Screw Gauge, pieces of wire, small regular solids like cylinders, cubes, spheres.

(1) Vernier Calipers

Description :—The Vernier Calipers consists of a flat, polished steel bar P about 10 to 15 cms. long, 1 cm. broad and about $\frac{1}{4}$ cm. thick. The main scale is marked on it, in cms. and mms. on one edge and in inches and its subdivisions on the other edge. The divisions on the scale commence at a distance of about a cm. from one end. At this end, the calipers is provided with a fixed jaw A with a plane face on the inner side. Sliding over the calipers is a vernier bit with the vernier scales marked on it on either edge. The vernier bit has a screw at the top by which it can be fixed on

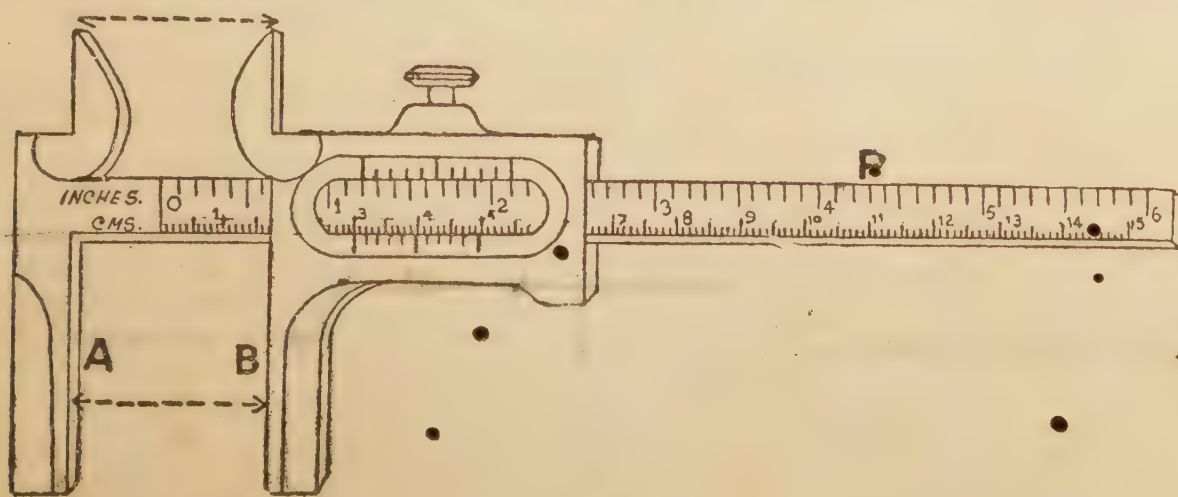


Fig. 1

the calipers in any position. The vernier bit also has a jaw B with a plane face. When the two jaws are in contact, the zeros on the vernier scales coincide with the corresponding zeros on the main scales. The jaws are intended to hold the object, the distance between the jaws being equal to the length of the object. Since

the zeros coincide, when the jaws are in contact, the distance between the jaws in any position is obviously equal to the reading on the main scale of the zero of the vernier.

Procedure :—Examine the main scale on the calipers and find the value of the smallest division on the inch scale. Count the number of divisions on the vernier scale. Make the zero of the vernier scale coincide with a definite division on the main scale. Find the number of divisions on the main scale covered by the divisions on the vernier scale. Calculate the value of one vernier scale division and find the difference between one main scale division and one vernier scale division. This will give the *least count* of the inch vernier. Find likewise the least count of the cm. vernier.

Make the two jaws just touch each other. See if the two zeros coincide. If they do, the instrument has no zero error. If they do not coincide, find out the position of the vernier zero on the main scale. Also note which division on the vernier coincides with a main scale division. This reading will give the zero reading of the instrument. It is equal to the number of whole divisions on the main scale from its zero + the coinciding vernier division multiplied by the least count. If this zero reading is positive, the zero correction is negative and *vice versa*.

Move the vernier bit on the scale, and place the solid (cylinder, sphere, etc.) whose dimensions (length, breadth, diameter, etc.) are required, in the gap between the jaws. Grip it firmly between the two jaws. Note the position of the zero of the vernier on the main scale and the coinciding vernier division. The reading of the nearest main scale division (on the zero side of the scale) + the coinciding vernier division multiplied by the least count is the actual reading. Change the position of the solid, grip the jaws again and note the reading as before. Take half a dozen readings for different positions of the solid.

Tabulate the readings as follows :—

		cm. scale	Inch scale
1 main scale division	=	cms. ;	inches
1 vernier scale division	=	"	"

		cm. scale	Inch scale
Least count (i.e. 1 main scale division—1 vernier scale division)	=	cms. ;	inches
Zero reading	=	„	„
Zero correction	=	„	„

Dimensions of a cylindrical solid :—

Object	Cm. Scale Reading			Inch Scale Reading		
	Main scale	Vernier scale	Total	Main scale	Vernier scale	Total
Length 1 2 3						
Diameter 1 2 3						
Mean				Mean		

Average length of cylinder = Mean reading of instrument } $\pm$ Zero correction

Average diameter „ = „ $\pm$ „

Repeat for the other solids given.

Special Verniers :—Ordinarily, the least count of a vernier is the difference between 1 main scale division and 1 vernier scale division. But, sometimes, you come across a cm. vernier, which has 10 divisions on it equal to 19 mms. on the scale. In this case the least count is the difference between two main scale divisions and one vernier scale division. The advantage in such a vernier is, that since the vernier divisions are large, coincidences can be judged more easily. Such vernier scales are usually found in some Barometer scales, Vernier Microscopes, etc. Examine such verniers, if available.

Spectrometer Vernier :—The principle of the vernier can be also used for the measurement of angles accurately. The least count is the difference between a main scale division and a vernier scale division. Examine the circular scale and the vernier attached to it in a Spectrometer and find the least count.

(2) Screw Gauge

Description :—The Screw Gauge consists of a *U* shaped steel frame *C* with a hollow cylindrical tube *D* projecting from one arm of the *U*.¹ The tube

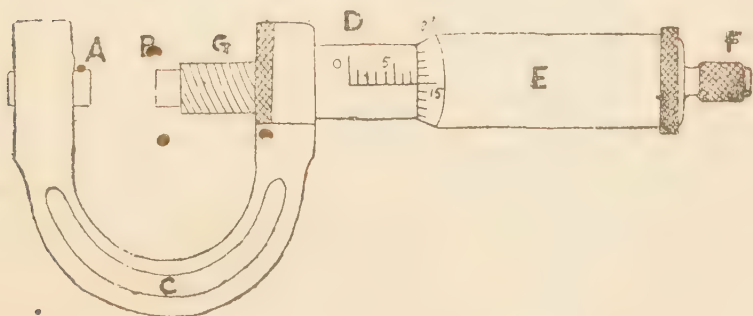


Fig. 2

has a screw thread, on its inside surface, through which a shaft *G* works. The shaft ends in a flat surface *B*. It has a sleeve or head *E*, which advances or recedes

over the tube when rotated. A linear scale known as the *pitch scale* is marked on the tube along its length. The sleeve has a bevelled edge *M* with a scale, known as the *head scale* or circular scale, marked all round it. The sleeve has a safety screw head *F* at its end. The zero on the head scale coincides with the zero on the pitch scale, when the end *B* of the shaft is in contact with the flat button *A* on the other arm of the *U*. When *B* and *A* are in contact, the safety screw-head *F* will rotate without *E* rotating, thus preventing undesirable tightening of the shaft.

Procedure :—Find the value of each pitch scale division. Rotate the head scale over the pitch scale *n* times so that it passes over a definite number of divisions on it. From this, find the *pitch* of the screw gauge. This is equal to the distance advanced by the head scale on the pitch scale during one complete rotation. The pitch divided by the number of divisions on the head scale is the *least count*. Rotate the head scale till *B* and *A* are in contact and there is no gap between them. When the gap closes, it will be indicated by the safety screw-head *F* rotating by itself, without the sleeve *E* advancing. In this position, the zero of the head scale will coincide with the zero of the pitch scale. If it does

not, the instrument has a zero error. Note the division on the head scale which lies on the pitch scale. This multiplied by the least count gives the zero reading. This may be positive or negative. The zero correction is this reading with its sign reversed.

To find the diameter of a small steel sphere or a wire, introduce it in the gap between *A* and *B*. Rotate the sleeve till the object is firmly but gently gripped. The safety screw-head *F* will help to prevent undue pressure on the object. Take the pitch scale reading. Note the division on the head scale which lies on the pitch scale. This multiplied by the least count gives the head scale reading. Change the position of the object and take the reading. Repeat half a dozen times.

Tabulate the results as follows :—

1 Pitch scale division	=	mms.
Pitch of the screw gauge	=	„
Least count of the screw gauge	=	„
Zero reading	=	„
Zero correction	=	„

Diameter of a steel ball :—

Trial No.	Pitch scale Reading mm.	Head scale Reading mm.	Zero correction mm.	Corrected Total Reading mm.
1				
2				
3				
4				
5				
6				
Mean				

Find the diameter of a steel wire in a similar manner. Take readings at half a dozen places and tabulate the results. Find the mean diameter of the wire.

EXPERIMENT 2

SPHEROMETER

Aim :—To determine (1) the thickness of a thin plate (2) the radii of curvature of spherical surfaces.

Apparatus required :—Spherometer, Thick glass plate, thin plates, Concave and Convex mirrors.

Description :—The spherometer is a handy instrument used for the accurate measurement of small thicknesses or heights. A

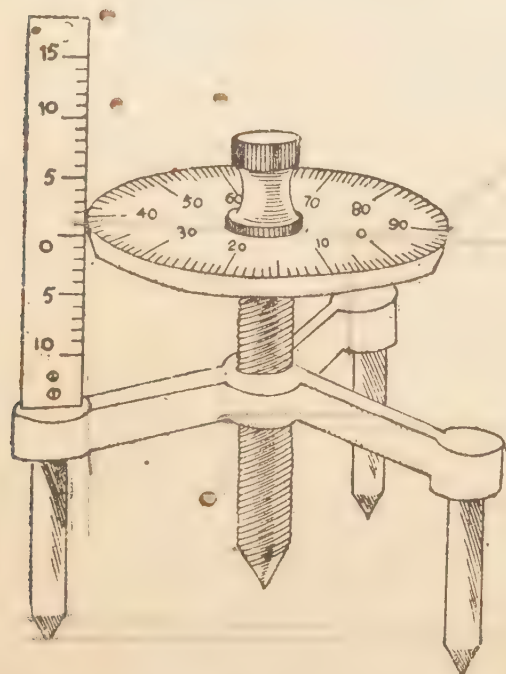


Fig. 3

pointed micrometer screw with fine, equidistant threads works in a nut situated at the centre of a platform, supported on three legs of equal height and with sharp ends. The legs are equidistant from each other and from the centre of the nut, their ends forming the vertices of an equilateral triangle. The head of the screw is a circular graduated disc which moves parallel to the edge of a short, vertical, linear scale fixed on one of the legs. This scale is graduated, the scale divisions being

equal to either the *pitch* or *multiples of the pitch* of the screw. When the central leg rests on the plane passing through the tips of the three fixed legs, the zero of the head scale and the zero of the disc scale will coincide.

Procedure :—Examine the linear pitch scale of the instrument and find out the value of each small division on it. Adjust the position of the head scale, so that the zero in it stands opposite to any observed division on the pitch scale. Rotate the head n times so that it passes over an integral number of divisions on the linear scale. The number of divisions passed over divided by the number of rotations gives the *pitch* of the spherometer. The pitch divided by the number of divisions on the head scale is the *least count* of the spherometer. Place the spherometer on a thick plane glass plate so that the three outer legs rest on it. Rotate

the head till the central leg just touches the plate. This can be ascertained by gently tapping one of the outer legs in a horizontal direction with the tip of the index finger. The whole instrument will show a tendency to spin round the central leg, if it touches the glass plate. With practice, the correct position can be easily judged. Rotation of the head scale by one or two divisions on it either way will make the outer legs either stick or spin freely round the central leg. The reading on the pitch scale + the reading on the head scale (i.e. the coinciding division multiplied by the least count) will give the zero reading of the instrument. Repeat by raising the central leg and lowering it again. Take three such readings. In a new spherometer, the zero of the head scale and the zero of the pitch scale will coincide when all the four legs are in the same plane. But with use, the zero reading is likely to alter. So, it must be taken every time the instrument is being used.

Tabulate as follows :—

Each Pitch Scale division = cms.

Number of rotations of Head Scale =

Number of divisions covered on the }
Pitch Scale =

$$\therefore \text{Pitch} = \frac{\text{Number of divisions covered on the Pitch Scale}}{\text{Number of rotations.}}$$

Total Number of divisions on Head Scale =

$$\therefore \text{Least count} = \frac{\text{Pitch}}{\text{Number of divisions on Head Scale}}$$

Zero Reading :—

No. of Trial	Reading on Pitch Scale	Reading on Head Scale	Total

$$\therefore \text{Average Zero Reading} =$$

(1) **Thickness of a thin glass plate :—** Having found the zero reading, raise the central leg and introduce under it the given thin plate. The three outer legs must rest on the plane glass reference plate. The thin plate must rest squarely on the plate under it. There should be no gap between the two. Lower the central leg

till it touches the thin plate, as ascertained by the spinning test. Note the readings on the pitch scale and on the head scale. Repeat by shifting the position of the thin plate so that the central leg touches a different part in it. Take at least six readings and tabulate them.

No. of Trial	Reading on Pitch Scale	Reading on Head Scale	Total
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Take the average. Then,

$$\left. \begin{array}{l} \text{Thickness of given} \\ \text{plate} \end{array} \right\} = \left. \begin{array}{l} \text{The above average} \\ \text{reading} \end{array} \right\} - \left. \begin{array}{l} \text{The Zero} \\ \text{reading} \end{array} \right\}$$

Repeat the experiment for two or three different plates.

(2) Radii of curvature of Convex and Concave mirrors :—

Note the zero reading of the spherometer by placing it on a plane glass plate. Raise the central leg sufficiently high and place the spherometer on the given convex mirror, with the three outer legs resting on it. Lower the central leg gently so that it just touches the surface of the mirror, ascertained by the spinning test. Note the readings on the pitch scale and the head scale and add them. Repeat by raising and lowering the central leg and also by shifting the spherometer to a different position on the mirror. Take about six readings and take their average. The difference between this reading and the zero reading gives the height h of the central leg above the plane containing the three outer legs, when they rest on the convex mirror. Then, place the spherometer on a sheet of paper, with all the four legs touching its surface. Press the instrument *gently* so that the four legs leave their marks on the paper. Remove the instrument. Measure with a scale the distances between the central leg and each of the outer legs and take the average. Measure also the distances between each pair of the outer legs and take the average. The distance between the central leg and any one of the outer legs is the radius r of the circle passing through the tips of the outer legs. The distance between any two of the outer legs is the length l of the equal sides of the equilateral triangle formed by the outer

legs. The radius of curvature R of the spherical surface is given by the following formulae.

$$R = \frac{r^2}{2h} + \frac{h}{2} \quad \text{or} \quad \frac{l^2}{6h} + \frac{h}{2}$$

Repeat the experiment with the concave mirror. Here, lower the central leg till it just touches the surface of the mirror. Take the readings on the pitch scale and the head scale. Since the tip of the central leg is below the plane containing the tips of the other three legs, the reading will be negative. The difference between the above reading and the zero reading will give the depth h of the tip of the central leg below the plane passing through the tips of the outer legs, when all the four legs rest on the concave surface. Take about six readings for h and take their average. Calculate R , using the formulae,

$$R = \frac{r^2}{2h} + \frac{h}{2} \quad \text{or} \quad \frac{l^2}{6h} + \frac{h}{2}$$

Tabulate the results as follows :—

Pitch of Spherometer	= 0.5 mm.
Number of divisions on Head Scale	= 100
∴ Least count	= 0.005 mm.
Zero reading	= + 0.005 mm.
Average distance l between outer legs	= 3.93 cms.

I. Convex mirror

No. of Trial	Reading on Pitch Scale	Reading on Head Scale	Total
1	0.5 mm.	74 dns.	0.870 mm.
2	0.5 „	72 „	0.860 „
3	0.5 „	71 „	0.855 „
4	0.5 „	71 „	0.855 „
5	0.5 „	67 „	0.835 „
6	0.5 „	68 „	0.840 „
Average			0.853 mm.

$$\begin{aligned}
 \therefore \text{Average height } h \text{ of the convex surface} &= 0.853 \\
 &\quad - 0.005 \\
 &\quad \hline
 &\quad 0.848 \text{ mm.} \\
 &\quad \hline
 &= 0.0848 \text{ cm.}
 \end{aligned}$$

$$\begin{aligned}
 \therefore R &= \frac{3.93^2}{6 \times 0.0848} + \frac{0.0848}{2} \\
 &= 30.35 + 0.04 \\
 &= 30.39 \text{ cms.}
 \end{aligned}$$

$\therefore$ The radius of curvature of the convex mirror is 30.39 cms.

II. Concave mirror

No. of Trial	Reading on Pitch Scale	Reading on Head Scale *	Total
1	—0.5 mm.	—85 dns.	—0.925 mm.
2	—0.5 "	—60 "	—0.800 "
3	—0.5 "	—95 "	—0.975 "
4	—0.5 "	—45 "	—0.725 "
5	—0.5 "	—70 "	—0.850 "
6	—0.5 "	—80 "	—0.900 "
Average			—0.863 mm.

* The reading on the head scale, will be the difference between 100 and the coinciding division.

$$\begin{aligned}
 \therefore \text{Average depth of the concave surface} &= -0.863 \\
 &\quad -0.005 \\
 &\quad \hline
 &\quad -0.868 \text{ mm.} \\
 &\quad \hline
 &= -0.0868 \text{ cms.} \\
 &\quad \hline
 \end{aligned}$$

$$\begin{aligned}
 \therefore R &= \frac{3.93^2}{6 \times 0.0868} + \frac{0.0868}{2} \\
 &= 29.66 + 0.043 \\
 &= 29.70 \text{ cms.}
 \end{aligned}$$

$\therefore$ The radius of curvature of the concave mirror is 29.70 cms.

Note :—The zero of the pitch scale is in the middle of the scale with divisions marked above and below it. So, readings taken with convex surfaces are positive and those with concave surfaces negative. This is likely to confuse the beginner. So, till the student becomes thoroughly familiar with the use of the

spherometer, it will be more convenient, if the lowest division on the pitch scale is taken as the zero. Then, all the readings taken will be positive and the student will have less confusion.

EXPERIMENT 3

OPTIC LEVER

Aim:—(1) To measure the thickness of thin plates using (a) a single optic lever and (b) a double optic lever, with a telescope and scale and (2) to determine the radius of curvature of a convex surface using a double optic lever.

Apparatus required:—Single optic lever, Double optic lever, thin glass or metal plates, Convex surface.

(a) Single optic lever

Description:—The single optic lever, in its simple form, is a triangular or rectangular metal plate having three pointed legs, forming the vertices of an elongated isosceles triangle. Two of the legs are close together and the line joining them is parallel to the base of the plate. A plane mirror is mounted on the plate perpendicular to it, in the plane passing through the two legs. The third leg is at the other end of the plate.

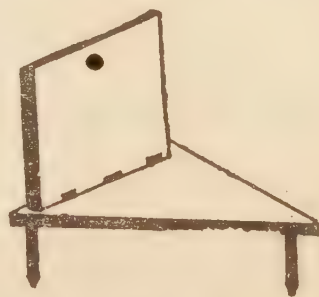


Fig. 4

Procedure:—Place the optic lever on a plate of thick glass. Set up a stand with a telescope and a scale at a distance of about a metre from the optic lever facing the mirror in it. Keep the scale vertical. Turn the telescope so that its axis passes through the centre of the mirror. Adjust the eye-piece so that the cross-wires are distinctly seen, and one of them is vertical and the other horizontal. Focus the telescope on the image of the scale seen in the mirror. Tilt the telescope, so that the horizontal cross-wire coincides with any division on the scale. Note this reading. Gently raise the third leg of the lever, without disturbing the other two legs and introduce the thin plate under it. The third leg is thus raised through a height equal to the thickness of the plate while the other two legs retain their original positions. So, the mirror gets tilted through a small angle. The reflected ray is

rotated through twice the angle. The cross-wire of the telescope now coincides with a different division on the scale. Note the reading. Shift the position of the plate carefully and again take the reading on the scale. Take half a dozen readings corresponding to different positions on the plate. Let the average shift in the scale division be d .

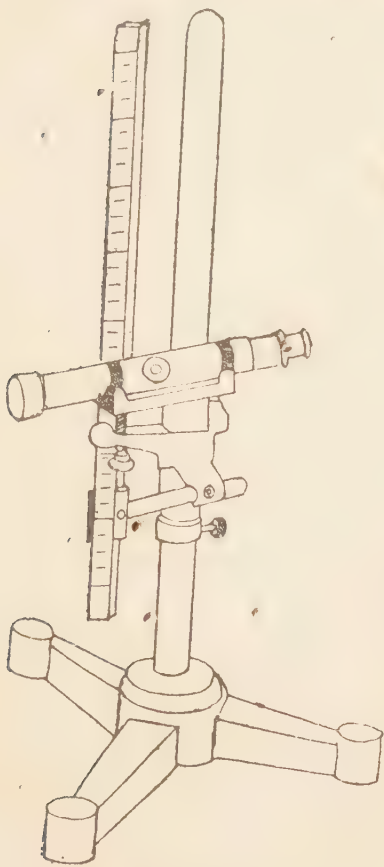


Fig. 5

Calculations :—Measure D the distance between the mirror and the scale. Place the optic lever on a piece of paper and press it. The legs leave their marks on the paper. Measure the perpendicular distance l between the third leg and the plane containing the other two legs. Then, if t is thickness of the plate,

$\frac{t}{l}$ is the angle through which the plane mirror fixed to the optic lever is tilted.

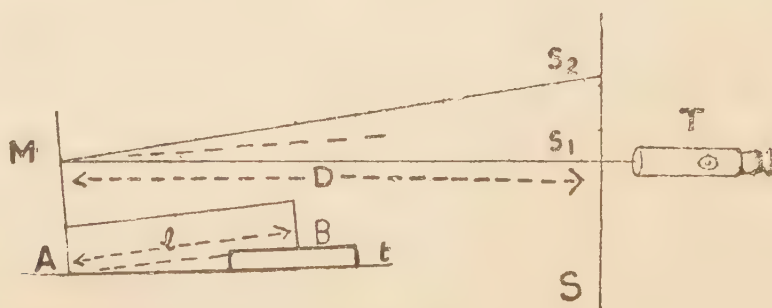


Fig. 6

$\frac{2t}{l}$ is the angle through which the reflected ray is rotated.

$$\therefore \frac{2t}{l} = \frac{d}{D} \quad \text{or} \quad t = \frac{l \times d}{2D}$$

Repeat the experiment with other plates, and measure their average thicknesses.

Tabulate the readings as follows :—

$l =$ cms ; $D =$ cms.

No. of Trial	Initial scale reading	Final scale reading	Difference d	$t = \frac{d \times l}{2D}$

(b) Double optic lever

Description :—The double optic lever, in its simple form, is a diamond shaped or rectangular metallic plate, mounted on four



Fig. 7

pointed legs, their feet representing the corners of an elongated rhombus. The two central legs form the shorter diagonal of the rhombus and are slightly longer than the two outer legs, so that, when placed on a plane surface, the optic lever rests only on three of the legs, i.e., the two central and one of the outer legs. Hence it is slightly inclined to the horizontal. A plane mirror strip is fixed on the lever perpendicular to it on the line joining the two central legs.

Procedure :—Place the optic lever on a plane glass plate, with the two central legs and one of the outer legs resting on it. Set up the stand carrying the telescope and the vertical scale in front of the optic lever at a distance of about a metre from it. Turn the telescope so that its axis passes through the centre of the mirror. Adjust the eye-piece so that the cross-wires are distinctly seen and one of the cross-wires is horizontal and the other vertical. Tilt the telescope so that the horizontal cross-wire coincides with any division on the scale. Note the reading. Gently push down the optic lever at the end where the leg does not rest on the plate, so that that leg now rests on the plate. The lever gets tilted and the plane of the mirror changes. Hence, the reading on the scale will be different. Note the reading.

Now, gently raise the central legs and introduce the thin plate under it, without disturbing the position of the optic lever. Again, note the readings on the scale when the optic lever rests on one of the outer legs and, then, on the other.

Calculations :—Let l be half the distance between the two outer legs and x the difference in vertical height between the inner legs and the outer. Then, when the optic lever rests on the inner legs and one of the outer legs, the angle that it makes with

the horizontal will be $\frac{x}{l}$. This will also be the angle which the mirror makes with the vertical. When the optic lever is gently swung about the central legs so as to make it rest on the other outer leg, the mirror will turn through an angle equal to $\frac{2x}{l}$.

The reflected ray will turn through $2 \times \frac{2x}{l}$ or $\frac{4x}{l}$.

$$\therefore \frac{4x}{l} = \frac{d_1}{D} \quad \text{or} \quad x = \frac{l \times d_1}{4D}$$

where d_1 is the shift in the scale division and D , the distance between the mirror and the scale.

When a thin plate of thickness t is placed under the central legs, the difference in height between the central legs and the outer becomes $(x + t)$. If the shift in the scale division is d_2 , then,

$$\frac{4(x + t)}{l} = \frac{d_2}{D} \quad \text{or} \quad (x + t) = \frac{l \times d_2}{4D}$$

$$\therefore t = \frac{l(d_2 - d_1)}{4D}$$

Thus t can be calculated. Take a number of readings by shifting the position of the plate under the central legs and find the average value of t .

Radius of curvature of a convex surface

The radius of curvature of a convex surface can be determined using the double optic lever. Place the optic lever on the surface with the two central legs and one of the outer legs resting on it. Note the reading on the scale. Gently, swing the lever about the central legs, so that the other outer leg touches the surface. Note the reading. Let d_1 be the shift in the reading of the scale division when the optic lever is placed on a plane surface and d_2 , when, placed on the convex surface. Take out the optic lever and press it on a sheet of paper, so that all the four legs leave their marks on it. Measure the distances between the two outer legs and the two central legs. Let them be $2l$ and $2b$ respectively.

Then,

$$R = \frac{(l^2 - b^2) \times 2D}{(d_2 - d_1) \times l}$$

Place the optic lever at different points on the surface, note the average value of d_2 and calculate R .

The above formula is derived as follows :—

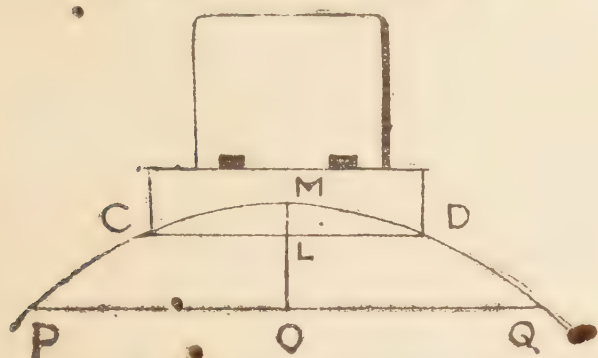


Fig. 8 (i)

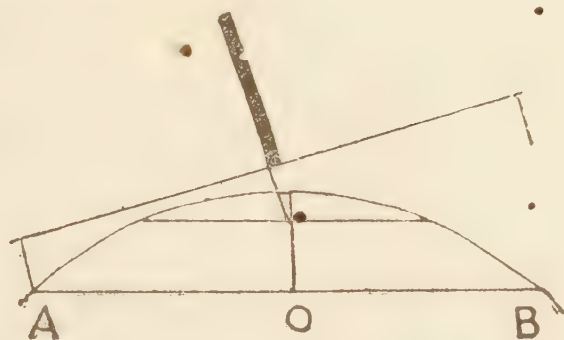


Fig. 8 (ii)

In fig (i), C and D represent the points where the two inner legs rest on the surface. If $CD = 2b$, then

$$(2R - LM) LM = b^2 \text{ or } 2R \cdot LM = b^2 \text{ (i) (neglecting } LM^2).$$

In fig (ii), A and B represent the points where one or the other of the outer legs rest on the surface. $AB = 2l$. Then,

$$(2R - OM) OM = l^2 \text{ or } 2R \cdot OM = l^2. \quad \text{(ii)}$$

PQ is a chord perpendicular to AB, through O, the mid-point of AB. $PQ = AB$. OL is the difference in vertical height between the outer legs and the inner legs. If d_1 and d_2 are the differences in the readings on the scale when the optic lever is placed on a plane surface and on the convex surface, then

$$OL = \frac{(d_2 - d_1) \times l}{4D}.$$

$$\text{Now, } 2R (OM - LM) = l^2 - b^2$$

$$\therefore 2R \times OL = l^2 - b^2$$

$$\therefore 2R \times \frac{(d_2 - d_1) \times l}{4D} = l^2 - b^2$$

$$\therefore R = \frac{(l^2 - b^2) \times 2D}{(d_2 - d_1) \times l}$$

EXPERIMENT 4

BALANCE

Aim:—(a) To determine the weight of a body correct to three and four places of decimals and to apply correction for the buoyancy of air ; (b) To draw the load-sensitivity curve for the balance.

Apparatus required:—The common balance, weight-box, the body to be weighed.

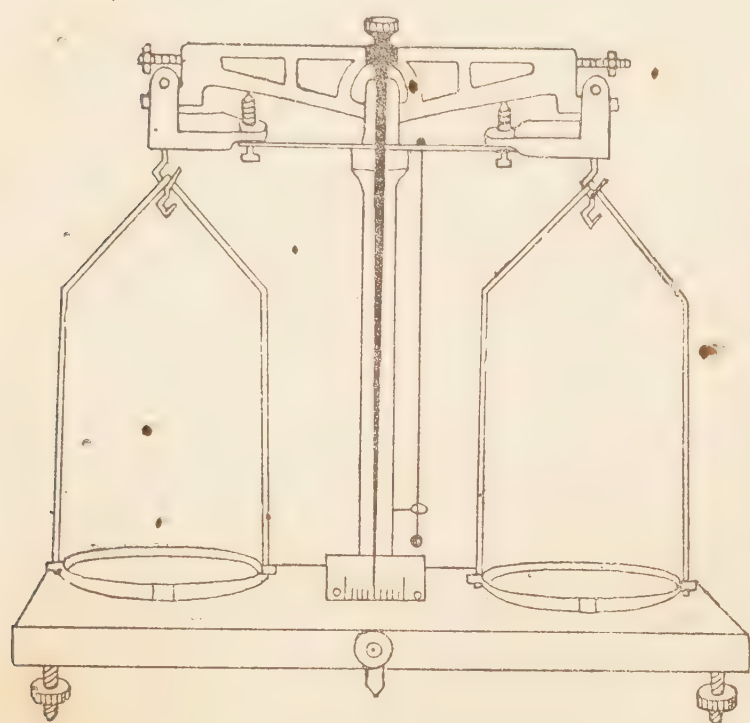


Fig. 9

Description:—The weight of a body can be determined very accurately using the common balance. It consists of a rigid, horizontal beam resting symmetrically, from an agate knife edge, on an agate platform fixed to the top of a cylindrical rod sliding inside a hollow, vertical, fixed, cylindrical pillar. Two scale pans of equal masses are hung at the two

ends of the beam from stirrups resting on agate knife edges. To the centre of the beam is attached a long, vertical pointer whose end moves over a small ivory scale. When not in use, the beam is at rest and the scale pans rest on the base-board or on short supports fixed to the base-board. By a lever arrangement the rod supporting the beam can be raised. The beam and the scale pans then get released. The beam swings about the fulcrum and the vertical pointer attached to it moves in front of the scale. The beam is symmetrical about its centre. The scale pans and the stirrups are of equal masses. So, when the beam is raised, it will be horizontal and the pointer vertical. When set in vibration, it will swing equally about its position of rest. When equal masses are placed on the scale pan, they will balance each other and the pointer will again swing symmetrically. The beam is provided with two small adjustable nuts at its ends. If the pointer does not swing equally on both sides of the centre, the nuts can be adjusted and the defect remedied. When not in use, the beam is lowered and arrested. To adjust the beam to be horizontal, the base-board is provided with levelling screws and a plumb line is suspended by the side of the central pillar.

Procedure :—When the beam is raised, the pointer swings in front of the scale on both sides of the centre. The division on the scale opposite to which the pointer ultimately comes to rest is its *Resting Point*. In a good balance, however, there will be very little friction between the knife-edges and the planes on which they rest. So, the pointer will make a large number of oscillations before it comes to rest. Hence, the resting point is found by noting an odd number, say 3 or 5, of consecutive turning points on both sides. The mean of the average left turning point and the average right turning point is the resting point. The resting point observed when the pans are empty is the *Zero Resting Point*. When equal weights are placed on the scale pans, the resting point must be the same as the Zero Resting Point.

(a) (1) **Weight of a body :—**To find the weight of a body, place it on the left hand pan. Place known weights on the right hand pan. Begin with a weight larger than that of the body, reducing it till the pointer swings within the scale, symmetrically about the Zero Resting Point. Note the resting point. If this resting point is to the left of the Zero Resting Point, remove 10 mgms. from the right hand pan and note the resting point. If it is to the right of the Zero Resting Point, add 10 mgms. Proceed thus and get two weights, differing by 10 mgms, for which the resting points will be on either side of the Zero Resting Point.

[**Note :—**The small weight, to be added to or removed from the right hand pan, to produce a shift in the resting point depends on the sensitiveness of the balance. It may vary from 20 mgms. to 1 mgm., depending on the balance. Analytical balances are provided with arrangements for placing a small rider, on the beam, at specified points, for increasing or decreasing the weight on the right hand pan. With such balances, weights can be determined correct to four places of decimals.]

From the shift produced in the resting point by 10 mgms., the weight required to shift one of the resting points to the Zero Resting Point is calculated by interpolation. It is added to or subtracted from the weight in the right hand pan and the correct weight of the body is found out. The readings are tabulated as indicated below.

I. Weight of a body correct to three places of decimals.

Weight on Left Pan	Weight on Right Pan	Turning Points		Resting Point
		Left	Right	
0 gm.	0 gm.	5.0 } 5.5 } 5.4 5.8 }	15.5 } 15.3 } 15.4	10.4
Body	140.84 gms.	4.0 } 4.5 } 4.5 5.0 }	19.0 } 19.0 } 19.0	11.8
Body	140.85 gm.	4.0 } 4.1 } 4.1 4.2 }	16.0 } 15.8 } 15.9	10.0

To produce a shift of 1.8 dns. 10 mgms. have to be added.

$$\therefore \quad \quad \quad 1 \text{ dn. } \frac{10}{1.8} \quad \quad \quad "$$

$$\therefore \quad \quad \quad 1.4 \text{ dns. } \frac{10 \times 1.4}{1.8} \text{ or } 8 \text{ mgms. must be added.}$$

$$\therefore \text{ Correct weight of the body } = 140.84 + .008 \\ = 140.848 \text{ grams.}$$

II. To find the weight of a body, using a Balance with a rider, correct to four places of decimals.

Weight on Left Pan	Weight on Right Pan	Turning Points		Resting Point
		Left	Right	
0 gm.	0 gm.	7.7 } 7.8 } 7.8 7.9 }	13.7 } 13.4 } 13.6	10.7
Body	44.105 gms.	8.2 } 8.4 } 8.5 8.8 }	15.1 } 15.0 } 15.1	11.8
Body	44.106 gms.	9.2 } 9.3 } 9.3 9.5 }	10.9 } 10.7 } 10.8	10.1

$$\therefore \left. \begin{array}{l} \text{Correct weight} \\ \text{of the body} \end{array} \right\} = 44.105 + \frac{0.001}{1.7} \times 1.1 = 44.1056 \text{ grams.}$$

[Note :—In some balances, the divisions on the scale may be too small to allow of estimation of the turning point correct to one decimal place. In such cases, give the turning point, correct to half of a division.]

(2) Correction for Buoyancy

The weight of a body determined thus has to be corrected for the buoyancy of air, to get its true weight in vacuum. Let W_1 be the weights added, d_1 their density, d the density of the body and s the density of air. Let W be the weight of the body in vacuum. Then,

$$\text{the apparent weight of the body in air} = W - \frac{W}{d} \times s$$

$$\text{the apparent weight of the weights in air} = W_1 - \frac{W_1}{d_1} \times s$$

These two are equal.

$$\begin{aligned} \therefore W \left(1 - \frac{s}{d} \right) &= W_1 \left(1 - \frac{s}{d_1} \right) \\ \therefore W &= \frac{W_1 \left(1 - \frac{s}{d_1} \right)}{\left(1 - \frac{s}{d} \right)} = W_1 \left(1 - \frac{s}{d_1} \right) \left(1 + \frac{s}{d} \right) \\ &= W_1 \left(1 - \frac{s}{d_1} + \frac{s}{d} \right) \end{aligned}$$

(since s density of air is very small compared with that of the weights or of the body.)

(b) Load-Sensibility curve

The sensibility of a balance is the shift in the resting point produced by the addition of 1 mgm. to either pan. This depends on the load on the pans. It is not constant. Generally, it slightly increases as the load increases from zero, gradually decreases, and finally becomes more or less constant. The resting point for any load is first determined as usual. A small weight, say 5 mgms. or 10 mgms. is added to either pan. From the shift in the resting point, the sensibility is calculated.

[Note :—It may happen, that, when apparently equal, large weights are placed on the two pans, the pointer does not swing within the scale. In such cases, the weights must be equalised, the

pointer made to swing within the scale and the sensibility determined.]

The load-sensibility curve is drawn by representing the load on the X axis and the corresponding sensibility on the Y axis.

Tabulate the results as follows :—

Load on each pan	Resting Point			Resting Point with 10 mgms. more in one of the pans			Shift in Resting Point	Sensibility
	Left Turning Point	Right Turning Point	Resting Point	Left Turning Point	Right Turning Point	Resting Point		
0 gms.								
10 "								
20 "								
50 "								
100 "								

EXPERIMENT 5

THE VERNIER MICROSCOPE

Aim :—To find the mean radius of the bore of a capillary tube using the Vernier Microscope (1) by direct measurement and (2) with a mercury thread.

Apparatus required :—Vernier Microscope, capillary tube, a small quantity of mercury, watch glass.

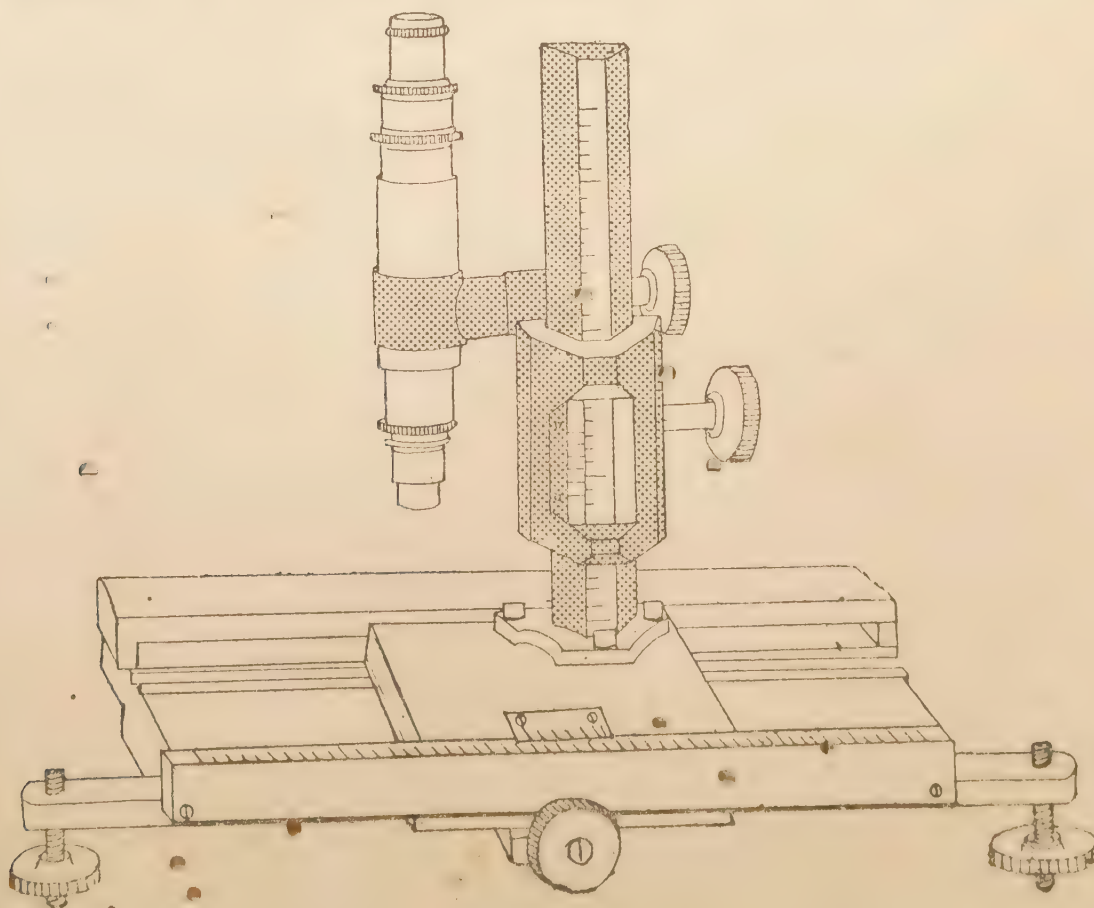


Fig. 10

Description of Apparatus:—The vernier microscope, in its usual form, consists of a low power microscope attached to a frame which can be moved up and down a vertical pillar with a scale marked on it and can be clamped in any position on it. The vertical pillar rests on a rectangular plate which can move to and fro by the side of a horizontal scale and can be clamped in any position. Thus, the microscope is capable of being moved in both the vertical and horizontal directions. Usually, rack and pinion arrangement is provided for both the vertical and horizontal motions. Vernier scales are provided for both the scales. The eye-piece has a cross-wire fixed in it. The microscope can be fixed with its axis either horizontal or vertical. The microscope is provided with a platform or stage on which objects can be placed and observed with the microscope in the vertical position.

(a) Radius of capillary tube by direct measurement

Procedure:—Fix the microscope with its axis horizontal. This is indicated by a reference line on the body of the microscope coinciding with a mark on the frame. Hold a white surface in front of the microscope and adjust the eye-piece so that the cross-wires are distinctly seen, one of them being horizontal and the other vertical. Mount the capillary tube horizontally in front of the microscope so that its axis and the axis of the microscope coincide. Focus the microscope on the mouth of the capillary tube.

Find out the least counts of the vernier scales attached to the vertical and horizontal scales. Work the microscope so that the vertical cross-wire is tangential to the bore at one end of it. Take the reading on the horizontal scale by reading the vernier. Move the microscope horizontally so that the same cross-wire is tangential to the bore at the other end. Take the reading. The difference in reading gives the diameter. Move the microscope vertically so that the horizontal cross-wire is tangential to the top of the bore. Take the reading on the vertical scale. Lower the microscope so that the same cross-wire is tangential to

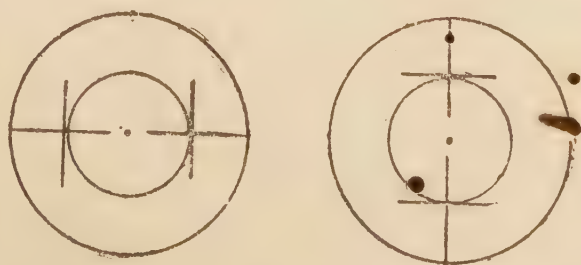


Fig. 11.

the lower end of the bore. Note the reading. The difference gives the diameter of the tube in the perpendicular direction. Rotate the tube and take one or two more set of readings. Turn the capillary tube so that the microscope is focussed on the other end. As before, take readings.

Tabulate the readings as follows :

Vertical Scale.				Horizontal Scale.		
Least count of vernier =				cms ;		cms.
Trial, No.	Vertical Scale.			Horizontal Scale.		
	Reading at top of bore	Reading at lower end of bore	Diffe- rence	Reading at left end of bore	Reading at right end of bore	Diffe- rence
1						
2						
3						
Mean				Mean		

∴ The mean diameter of tube = cms.

∴ The mean radius of tube = cms.

(b) Radius of capillary tube by mercury thread

Procedure :—The microscope is turned round so that its axis is vertical. This is indicated by a line on the body of the microscope coinciding with a line on the frame work. Adjust the eye-piece so that the cross-wires are distinctly seen. Draw a few cms. of clean, dry mercury into the capillary tube. Keep the mercury thread near one end of the tube. Place the tube on the platform of the microscope, under it, so that the tube is parallel to the axis of horizontal motion of the microscope i.e., parallel to the scale. Focus the microscope on the mercury thread. Move the microscope so that the vertical cross-wire is tangential to the mercury thread at one end. Note the reading. Move the microscope so that the vertical cross-wire is tangential

to the other end of the thread. Note the reading. The difference gives the length of the mercury thread. If a high degree of accuracy is required a correction has to be applied to allow for the convex meniscus. From the length of the thread, $2 \times \frac{r}{3}$ must be subtracted to get the correct length, where r is the radius of the tube. Tilt the tube gently and make the thread take up another position in the tube. Measure its length as before. Repeat, making the thread occupy different positions in the tube. Find the average length of the mercury thread.

Weigh a watch glass correct to three places of decimals. Transfer all the mercury from the tube to the watch glass and find the weight again correct to three places of decimals. The difference gives the weight of the mercury alone.

Calculations :—If l is the length of the mercury thread and r is the radius, the volume of mercury is $\pi r^2 l$. Its weight is $\pi r^2 l d$ where d is its density. Let W be the weight. Then

$$\therefore W = \pi r^2 l d$$

$$\therefore r^2 = \frac{W}{\pi l d}$$

$$\therefore r = \sqrt{\frac{W}{\pi l d}}$$

If l is the mean length of the thread, r will give the mean radius of the tube.

Tabulate the results as follows :—

Least count of microscope = 0.001 cm.

Trial No.	Reading of one end of thread	Reading of the other end of thread	Difference in reading
1	2.273 cms.	9.378 cms.	7.105 cms.
2	3.278 „	10.378 „	7.100 „
3	6.537 „	13.665 „	7.128 „
		Mean	7.111 „

$\therefore$ Mean length of mercury thread = 7.111 cms.

Weight of watch glass = 6.504 grms.

Weight of watch glass and mercury = 6.730 grms.

$\therefore$ Weight of mercury alone = 0.226 grams.

$$\therefore r = \sqrt{\frac{0.226}{3.1416 \times 7.111 \times 13.6}} = 0.0273 \text{ cms.}$$

$\therefore$ The mean radius of the tube is 0.0273 cms.

Have similar tabular forms for each tube, if more than one tube is given.

[If a correction is applied to allow for the convex meniscus, use the following formula :—length of thread = $\left(l - \frac{2r}{3}\right)$;

volume of mercury = $\pi r^2 \left(l - \frac{2r}{3}\right)$; weight of mercury

= $\left(\pi r^2 l - \frac{2\pi r^3}{3}\right) d = W$. To solve this, calculate r , ignoring

the correction for l . Correct l by using the approximate value of r . Use the corrected value of l and calculate r .]

EXPERIMENT 6

FORCES AT A POINT

Aim :—To verify (1) the Parallelogram Law of Forces, (2) the Law of Triangle of Forces, (3) the Lami's Theorem and (4) the Tangent Law.

Apparatus required :—Two smooth, light, frictionless pulleys, slotted weights, circular protractor.

Procedure :—Suspend the two pulleys from hooks on a rigid horizontal support, about 40 cms. apart. Take three strings and tie one end of each of them so as to form a small common knot. Pass two of them over the two pulleys. Suspend from the free ends of all the three strings suitable slotted weights, so that they are in equilibrium. With a circular protractor, held parallel to the plane of the strings, with the centre of the protractor just behind the knot in the same horizontal line, measure the angles between the strings. Let the forces be P , Q and R and the angles between

them be a , b , and c , a being the angle between Q and R , b the angle between P and R and c the angle between P and Q . On a sheet of paper fixed to a drawing board, draw straight lines representing the lines of action of the forces, with the help of the angles measured. Mark the directions and magnitudes of the three forces P , Q , R on the lines drawn. Change the positions of the pulleys and weights and take three or four readings.

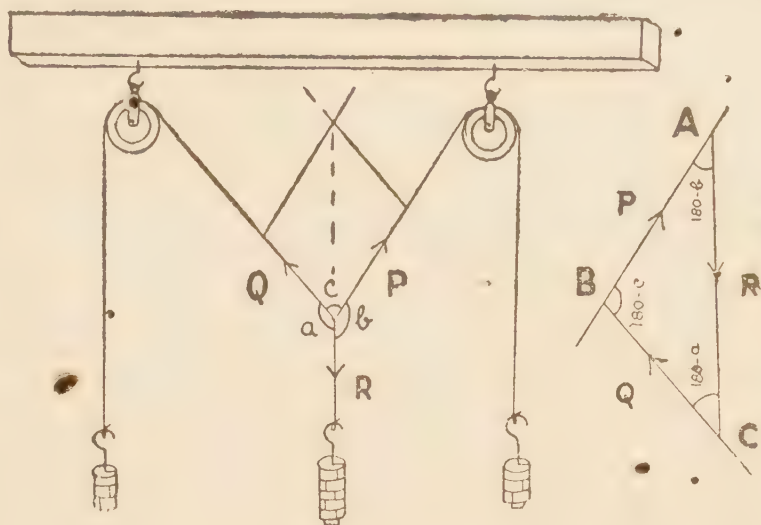


Fig. 12

(1) Parallelogram Law of Forces

Mark off on the lines representing P and Q , lengths proportional to P and Q on a suitable scale, and complete the parallelogram. Draw the diagonal through the point where P and Q meet. Measure its length and the angle between the diagonal and the third line representing R . This angle will be 180° and the length of the diagonal will be equal to the length of the line representing R .

Tabulate the results as follows :—

P	Q	R	Length of diagonal	Force represented by it on same scale R_1	Angle between R and R_1
grams wt.	grams wt.	grams wt.			

(2) Triangle of Forces

Draw a triangle ABC whose sides AB , BC , and CA are respectively parallel to the lines representing the forces P , Q and R . Measure the sides of the triangle. Then,

$$\frac{P}{AB} = \frac{Q}{BC} = \frac{R}{CA}$$

Tabulate the results :—

P	Q	R	AB	BC	CA	P	Q	R
grams wt.	grams wt.	grams wt.	cms.	cms.	cms.	AB	BC	CA

(3) Lami's Theorem

Find the sines of the angles a, b, c , the angles between the forces P and Q, Q and R, and R and P respectively.

Tabulate the results :—

P	Q	R	Sin a	Sin b	Sin c	P	Q	R
grams wt.	grams wt.	grams wt.				Sin a	Sin b	Sin c

(4) Tangent Law

Adjust the positions of the pulleys and the values of P and Q, so that the two strings to which P and Q are attached are perpendicular to one another. Measure the angle between P and the third force R. Let it be a . Then

$$P = R \cos a ; Q = R \sin a.$$

$$\text{and } \frac{Q}{P} = \frac{R \sin a}{R \cos a} = \tan a.$$

$$\therefore Q = P \tan a$$

Take three or four readings by altering P and Q and the positions of the pulleys.

Tabulate the results :—

P	Q	R	a			
grams wt.	grams wt.	grams wt.	(angle between P and R)	$R \sin a$	$R \cos a$	$P \tan a$

Alternative method :—Three strings are tied to a common knot. One of the strings is tied to a hook fixed on a rigid

support. From the second string a weight W is hung. Pass the third string over a pulley and fix it on a vertical stand at such a height that the string is perfectly horizontal (as tested by a spirit level). A weight P is attached to the end of this string. With the help of a plumb line hung from the hook, and a protractor, the angle between the first string and the vertical is measured. Let this angle be " a ". Then

$$P = W \tan a.$$

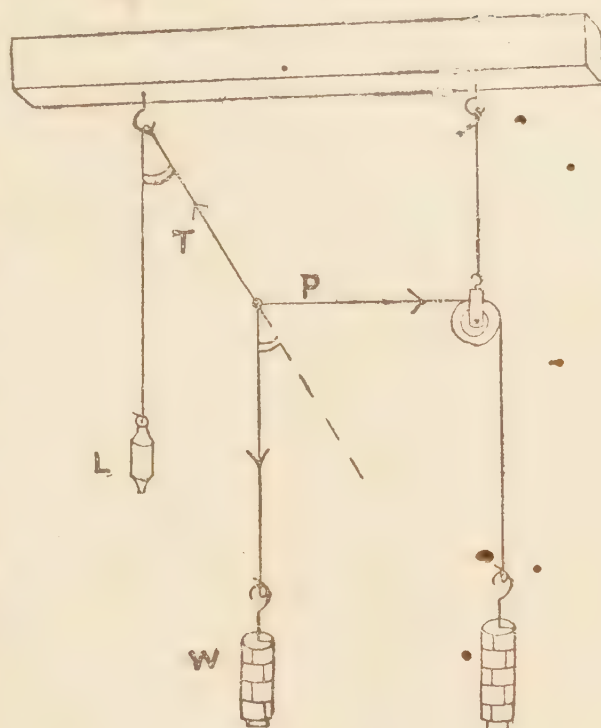


Fig. 13

Tabulate the results as follows :—

W	P	a	$\tan a$	$W \tan a$
grams wt.	grams wt.			

Having verified the law, it can be used for finding an unknown weight R using a known weight W . Suspend R in place of P . For W , add known weights so that the system is in equilibrium. Measure the angle " a " which the string tied to the hook on the fixed support makes with the vertical. Then, the unknown weight R is given by,

$$R = W \tan a.$$

By changing W , " a " will change. Keep the string horizontal. Take two or three readings and find the average value of R .

EXPERIMENT 7

PARALLEL FORCES

Aim :—(1) To verify the Law of Parallel Forces, (2) to verify the Conditions of Equilibrium of a body under the action of a system of coplanar, parallel forces, (3) to find the weight of a non-uniform bar and (4) to find the Centre of Gravity of a plane irregular lamina.

(1) Law of Parallel Forces.

Apparatus required :—A metre scale, two spring balances, slotted weights, loops of wire.

Procedure :—Suspend the two spring balances from hooks fixed to a rigid, horizontal support. Suspend the metre scale from

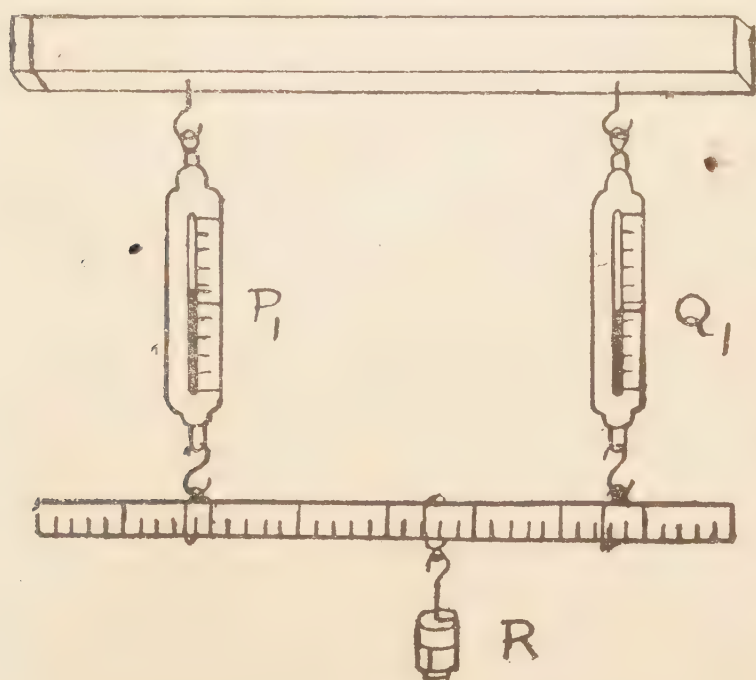


Fig. 14

the spring balances using the loops of wire. Note the initial readings in the spring balances. If they are p and q , their sum will be equal to the weight of the metre scale. Suspend a weight R from a loop of wire at any point on the scale. Adjust so that the spring balances are vertical and the metre scale horizontal. Note the tensions

P_1 and Q_1 in the spring balances. Then $(P_1 - p)$ and $(Q_1 - q)$ are the additional tensions due to R . Let them be P and Q respectively. Measure the distances from the point where the weight is hung, to the points where the metre scale is hung from the spring balances. Let them be a and b respectively.

Now, the resultant R of two like parallel forces P and Q is equal to their sum and it acts at a point on the line joining their points of application such that $P \times a = Q \times b$ where a and b are the distances between P and R , and Q and R respectively.

The resultant R of two unlike parallel forces P and Q is equal to their difference and it acts at a point on the line joining their points of application and produced, such that $P \times a = Q \times b$, where a and b are the distances between P and R , and Q and R respectively.

Change R and its position on the metre scale and take a number of sets of readings.

Tabulate the readings as follows for verifying the law relating to like parallel forces.

Initial reading of spring balance I = p .

Initial reading of spring balance II = q .

Weight hung R	Reading of spring balance I P_1	Reading of spring balance II Q_1	Force P $(P_1 - p)$	Force Q $(Q_1 - q)$	$P + Q$	a	b	$P \times a$	$Q \times b$
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To verify the law relating to two unlike parallel forces, the tension in spring balance I and the weight hung may be considered to represent two unlike parallel forces and the tension in spring balance II, their resultant. Similarly, the distance between one of the forces and the resultant will be $(a + b)$ and that between the other force and the resultant will be b . Thus, using the same readings, the law may be verified.

Tabulate as follows :

Weight hung R	Reading of spring balance I P_1	Reading of spring balance II Q_1	Force P $(P_1 - p)$	Force Q $(Q_1 - q)$	$R - P$	$\frac{a_1}{(a+b)}$	$\frac{b_1}{(b)}$	$P \times a_1$	$Q \times b_1$
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(2) Conditions of equilibrium of a body under the action of a system of coplanar parallel forces.

Apparatus required.—A long, uniform wooden rod of cross-section 1 sq. inch, two spring balances, slotted weights.

Conditions of equilibrium:—When a rigid body is in equilibrium under the action of a number of coplanar parallel forces, (1) the algebraic sum of the forces is zero and (2) the algebraic sum of the moments of the forces about any point in the same plane is zero.

Procedure :—Find the weight of the wooden rod using one of the spring balances. Since the rod is uniform, the weight acts at the centre of the rod. Suspend the spring balances from hooks fixed to a rigid, horizontal support, at a distance of about 75 cms. from each other. Suspend the wooden rod from the spring balances. Slotted weights are hung from various points on the rod from loops of thick wire slipped over the rod. Adjust the positions of the spring balances so that they are vertical. The rod

must be horizontal. Note the tensions in the spring balances. From any two points on the rod, say, one of the ends and the

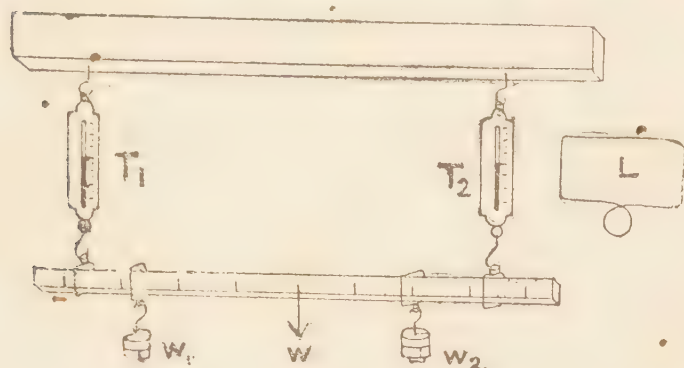


Fig. 15

centre, measure the distances of the points of application of each of the forces. The product of the force and perpendicular distance from any point to the line of application of the force is the moment of the force

about the point. If it is *clockwise*, it is considered *negative* and if, *anti-clockwise*, *positive*. Alter the weights and their positions and take three sets of reading,

Tabulate the results as follows :—

Force gms. wt.	Distance from one end of rod cms.	Moment about end	Distance from centre	Moment about centre
T_1	a	$T_1 \times a$	a_1	$T_1 \times a_1$
T_2	b	$T_2 \times b$	b_1	$T_2 \times b_1$
Weight of rod W	c	$W \times c$	c_1	$W \times c_1$
W_1	d	$W_1 \times d$	d_1	$W_1 \times d_1$
W_2	e	$W_2 \times e$	e_1	$W_2 \times e_1$
W_3	f	$W_3 \times f$	f_1	$W_3 \times f_1$
W_4	g	$W_4 \times g$	g_1	$W_4 \times g_1$
Algebraic sum of forces		Algebraic sum of moments		Algebraic sum of moments

For each set of readings, have a similar tabular form.

(3) Weight of a non-uniform bar

Apparatus required :—A non-uniform bar, slotted weights.

Procedure :—Pass a loop of wire over the bar and suspend it from a hook fixed to a rigid support. Using two more loops of wire, suspend from the bar, on either side of the point of support, two slotted weights W_1 and W_2 . Adjust their values and positions

on the bar, so that it is horizontal. Since the bar is in equilibrium, the algebraic sum of the moments of the parallel forces acting on it about any point on the bar is zero. Take moments about the point at which the bar is hung. The moment of the upward supporting force is zero about the point, since it passes through it. Let W be the weight of the bar. Find the centre of gravity of

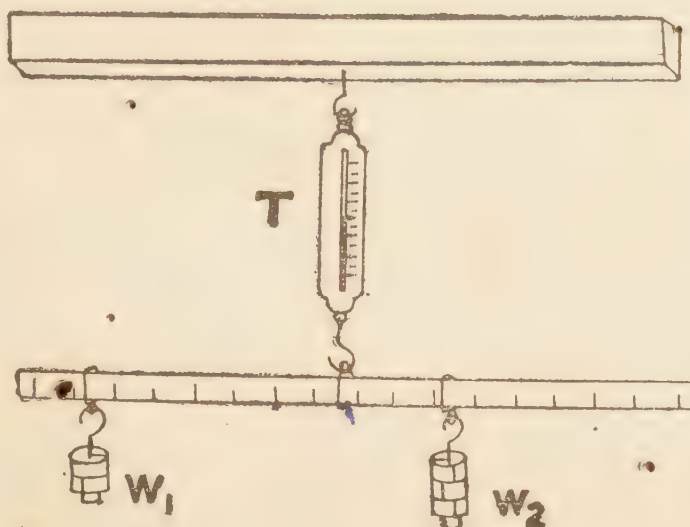


Fig. 16

the bar by balancing it on a knife edge. Let the distances of the lines of action of W_1 , W_2 and W from the point of support be a , b and c respectively. The moments are $W_1 \times a$, $W_2 \times b$ and $W \times c$ respectively. Their algebraic sum is zero. Let W_1 and W act on the rod on the same side of the spring balance. Then,

$$W \times c = W_2 \times b - W_1 \times a$$

$$\therefore W = \frac{W_2 \times b - W_1 \times a}{c}$$

Alter the values and the points of application of W_1 and W_2 , taking care to see that the bar is always horizontal. Measure a , b and c in each case.

Tabulate the results as follows :—

Weight W_1 grams wt.	Weight W_2 grams wt.	Distance a cms.	Distance b cms.	$W_1 \times a$	$W_2 \times b$	c cms.	$W = \frac{W_2 \times b - W_1 \times a}{c}$ grams. wt.
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The average of the values in the last column gives the weight of the bar.

(4) Centre of gravity of plane, irregular lamina

Apparatus required :—A plane irregular lamina, a plumb line.

Procedure:—Punch three or four tiny circular holes at different parts of the lamina. On a vertical, fixed stand drive a narrow nail. Support the lamina on the nail by passing it through one of the holes. The lamina should swing freely on the nail. Displace it so that it oscillates to and fro and comes to rest. Suspend the plumb line from the nail. It hangs vertically. Mark its outline on the lamina. Suspend the lamina about another hole. With the help of the plumb line, draw the vertical from the

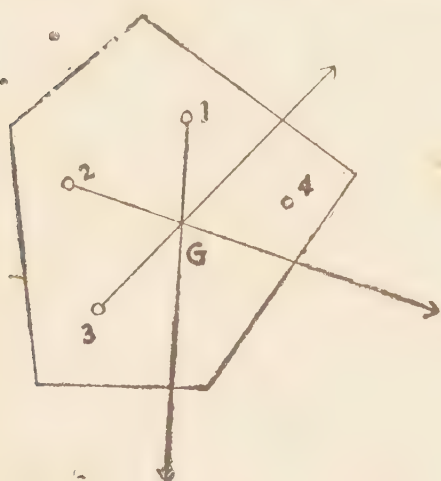


Fig. 17

axis of support, when the lamina hangs freely. The centre of gravity of the lamina must lie on each of the lines. So, the point of intersection G of the two lines gives the centre of gravity of the lamina. Verify by suspending the lamina from the third hole and drawing a vertical from it when it hangs freely. This line also must pass through the point of intersection G of the two lines.

EXPERIMENT 8

INCLINED PLANE

Aim:—To find the mechanical advantage of an Inclined Plane when the power acts (1) parallel to the plane and (2) horizontally.

Apparatus required:—Inclined Plane with roller, scale pan and a box of weights.

Description and Procedure:—The inclined plane consists of a rectangular base-board about 40 cms in length and 5 cms. in breadth, to which is attached by a hinge at one end another similar board about 50 cms. in length. A glass plate is fixed to the top of this board which functions as the inclined plane. By means of a vertical stand and clamp, the inclined plane can be fixed at any angle of inclination to the base board. A heavy brass roller is placed on the plane, and a string tied to it is passed over a small pulley fixed at the top of the plane. A scale pan is hung from the other end of the string. By adding a suitable

weight to the scale pan, the roller can be kept in equilibrium on the plane. In practice, this weight varies over a large range, depending on the friction between the plane and the roller. The provision of the glass plate is to reduce this friction. Even so, there will be an appreciable range. Hence, the force required to keep the roller in equilibrium is determined by noting the weights added when the roller just moves up the plane with uniform velocity and the weights added when the roller just moves down the plane with uniform velocity and taking their mean. The plane is fixed at various angles of inclination to the horizontal and the weight required to maintain the roller in equilibrium is determined. The weight of the roller is found by a spring balance.

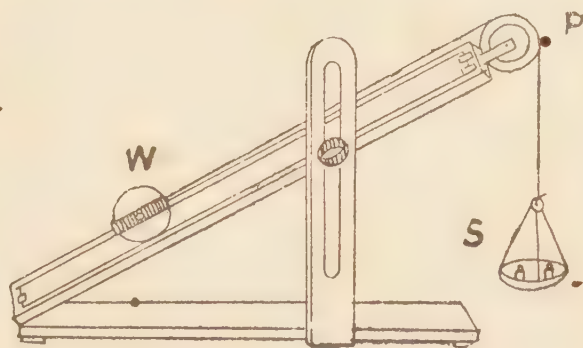


Fig. 18

The mechanical advantage $\frac{W}{P}$, when the power is applied parallel to the plane, is given by,

$$\frac{W}{P} = \frac{l}{h} = \frac{1}{\sin a}$$

Where W is the weight of the roller.

P is the weight required to keep the roller in equilibrium on the plane.

l is the length of the plane.

h is the vertical height of the top of the plane from the base.

a is the angle of inclination of the plane.

$$\therefore P = W \sin a \text{ or } P = \frac{W \times h}{l}$$

Tabulate the readings as follows :—

Angle of inclination a	Length of plane l	Vertical height of plane h	Weight of roller W	Force required to keep roller in equilibrium on plane			$W \sin a$	$W \times \frac{h}{l}$
				To move roller up P_1	To move roller down P_2	$P = \frac{P_1 + P_2}{2}$		

EXPERIMENT 9

SPECIFIC GRAVITIES OF SOLIDS AND LIQUIDS

Aim :—To determine the specific gravity of (1) an insoluble solid denser than water, (2) an insoluble solid which floats on water, (3) a liquid and (4) a soluble solid, using a hydrostatic balance.

Apparatus required :—Common balance, hydrostatic bench, an insoluble solid denser than water, a light insoluble solid (cork or wood), a soluble solid, a beaker of water and a beaker of liquid (in which the solid does not dissolve), paraffin wax, sinker, glass stopper.

Procedure :—(1) Specific gravity of an insoluble solid, denser than water.

Take a piece of thread and dip it in molten wax, so that it will not be wetted by water. Scrape the excess of wax and take two equal bits of the thread. Place them, one in each of the pans of the balance and find the zero resting point. Suspend the given solid from the hook of the left hand pan, using the string kept on it. Find the weight (W_1) of the solid correct to three places of decimals. Place the hydrostatic bench across the left hand pan without its touching the pan at any point. Place the beaker of water on it and introduce the suspended solid into the water. Care should be taken to see that (1) the solid hangs freely inside the liquid (2) no air bubbles are sticking to the solid and (3) the free movement of the pan is not obstructed in any way, when the beam is raised. Find the weight (W_2) of the solid in water.

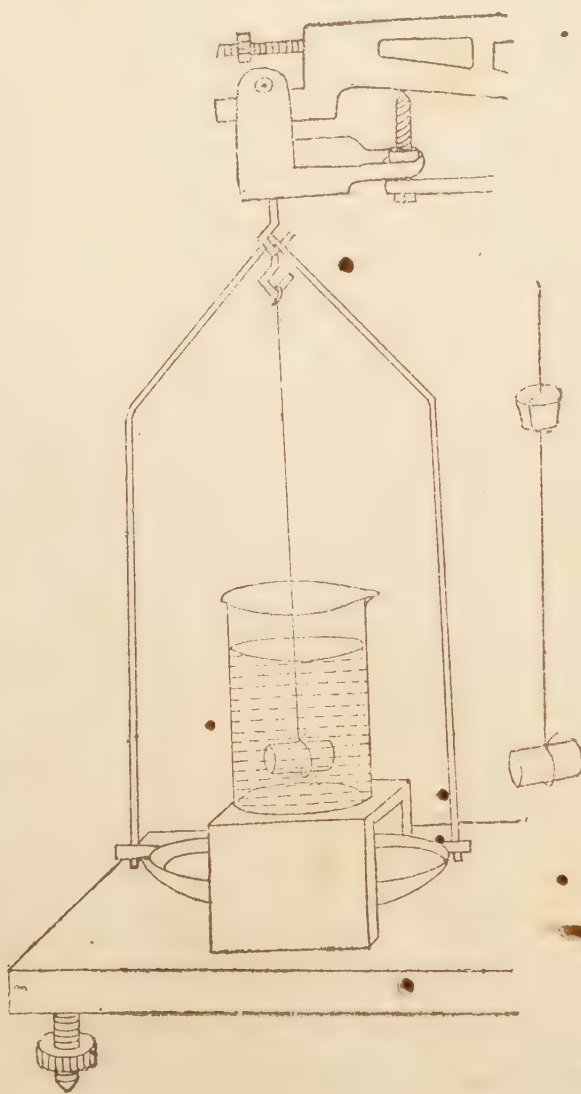


Fig. 20

Enter the readings as follows :—

$$\begin{aligned}
 \text{Weight of the solid in air} &= W_1 \\
 \text{Weight of the solid in water} &= W_2 \\
 \text{Loss of weight in water} &= (W_1 - W_2) \\
 \therefore \text{Specific gravity of the solid} &= \frac{W_1}{(W_1 - W_2)}
 \end{aligned}$$

(2) To find the specific gravity of a light solid
like cork or wood

Suspend a heavy solid from the hook in the left hand pan so that it is completely immersed in the beaker of water kept on the hydrostatic bench. Find the weight (W_1). Tie the cork to the string at such a place that the cork is in air and the sinker is under water. Find the weight (W_2). Then ($W_2 - W_1$) is the weight of the cork in air. Slip the cork down the string so that both cork and sinker are immersed in water. The weight of the sinker must be such that the cork and sinker are completely immersed inside water. Find the weight (W_3). Then ($W_2 - W_3$) will give the loss of weight of cork in water.

Enter the readings as follows :—

$$\begin{aligned}
 \text{Wt. of sinker in water} &= W_1 \text{ grams.} \\
 \text{Wt. of sinker in water and cork in air} &= W_2 \text{ grams.} \\
 \text{Wt. of sinker and cork in water} &= W_3 \text{ grams.} \\
 \text{Wt. of cork in air} &= (W_2 - W_1) \text{ grams.} \\
 \text{Loss of wt. of cork in water} &= (W_2 - W_3) \text{ grams.}
 \end{aligned}$$

$$\begin{aligned}
 \therefore \text{Specific gravity of cork} &= \frac{\text{Weight of cork in air}}{\text{Loss of weight of cork in water}} \\
 &= \frac{(W_2 - W_1)}{(W_2 - W_3)}
 \end{aligned}$$

(3) To find the specific gravity of a liquid.

Take a solid, say a glass stopper, which will not be acted on by the liquid. Suspend it from the hook of the left hand pan and find its weight (W_1) in air. Introduce the beaker of water under it on the hydrostatic bench and, taking the usual precautions, find the weight (W_2) of the glass stopper in water. Remove the beaker of water. Dry the solid and the string with filter paper, so that all traces of water are removed from them. Introduce the beaker

of liquid under the solid, so that the solid is immersed in the liquid. Find the weight (W_3) of the solid in the liquid.

Enter the readings as follows :—

Weight of solid in air	=	W_1
Weight of solid in water	=	W_2
Weight of solid in the liquid	=	W_3
Loss of weight of solid in water	=	$(W_2 - W_1)$
Loss of weight of solid in the liquid	=	$(W_3 - W_1)$
The loss of weight sustained by a solid when immersed in a liquid is equal to the weight of an equal volume of the liquid.		
∴ Specific gravity of liquid		

$$\begin{aligned}
 &= \frac{\text{Weight of a certain volume of liquid}}{\text{Weight of an equal volume of water}} \\
 &= \frac{\text{Loss of weight of the solid in the liquid}}{\text{Loss of weight of the solid in water}} \\
 &= \frac{(W_3 - W_1)}{(W_2 - W_1)}
 \end{aligned}$$

(4) To find the specific gravity of a soluble solid

(a) Using a liquid in which the solid does not dissolve :—

Suspend the soluble solid from the hook of the balance using a string. Find its weight (W_1) when it is suspended in air. Bring the beaker of liquid, in which it does not dissolve, under it on the hydrostatic bench and immerse the solid in it. Find the weight (W_2). Determine the specific gravity of the liquid by the method indicated previously *or* using a specific gravity bottle.

Enter the readings as follows :—

Weight of solid in air	=	W_1
Weight of solid in liquid	=	W_2
∴ Loss of weight of solid in liquid	=	$(W_1 - W_2)$
∴ Relative density of solid with respect to liquid	} = $\frac{W_1}{(W_1 - W_2)}$	

If s is the specific gravity of liquid,

$$\text{Specific gravity of solid} = \frac{W_1}{(W_1 - W_2)} \times s.$$

(b) Using paraffin wax for covering the solid.

Find the weight (W_1) of the solid alone in air, suspending it from the hook in the left hand pan. Dip it in molten paraffin wax, so that it gets completely coated with the wax. Suspend it

again and find the weight (W_2) of the combination. Place a beaker of water under it on the hydrostatic bench. Immerse it completely in it and find the weight (W_3). Determine the specific gravity (s) of the wax used, by an independent method.

Enter the readings as follows :—

$$\begin{aligned}
 \text{Wt. of solid in air} &= W_1 \\
 \text{Wt. of solid and wax in air} &= W_2 \\
 \therefore \text{Wt. of wax in air} &= (W_1 - W_2) \\
 \text{Wt. of solid and wax in water} &= W_3 \\
 \therefore \text{Loss of weight of solid and wax in water} &= (W_2 - W_3) \\
 \text{Loss of weight of wax alone in water} &= \frac{(W_1 - W_2)}{s} \\
 \therefore \text{Loss of weight of solid alone in water} &= (W_2 - W_3) - \frac{(W_1 - W_2)}{s} \\
 \therefore \text{Specific gravity of solid} &= \frac{W_1}{(W_2 - W_3) - \frac{(W_1 - W_2)}{s}}
 \end{aligned}$$

EXPERIMENT 10

SPECIFIC GRAVITY BOTTLE

Aim :—To determine the specific gravity of (1) a liquid and (2) insoluble and soluble solids in the form of small bits or powder.



Fig. 21

Apparatus required :—A specific gravity bottle, liquid, insoluble and soluble solids in small bits or powder which can be introduced into the bottle.

Description :—The specific gravity bottle is a small, glass vessel which can hold a definite volume of a liquid. It has a narrow mouth, the inside of it being ground. It is provided with a ground glass stopper, with a narrow hole at its centre, running through its length. If the bottle is filled with a liquid and the stopper slipped gently into it, the displaced liquid will escape through the central hole in the

stopper. With the stopper always in the same position, the bottle holds the same volume of liquid.

Procedure :—(1) **Specific gravity of a liquid.** Take a clean, dry specific gravity bottle. [If it is not clean, rinse it with some caustic soda solution to remove grease in it. Wash it with water and then, with some nitric acid or sulphuric acid. Again wash it thoroughly with water. Add a few drops of alcohol and dry it in a current of hot air]. Find its weight (W_1) correct to three places of decimals. Fill it completely with the liquid taking care to see so that no air bubbles are formed inside. Handle the bottle in the folds of a towel and gently slip in the stopper without exerting pressure on it. If it is handled with the bare hand, its warmth may produce expansion of the liquid. Clean well the outside of the bottle and find its weight (W_2) again. Remove the liquid from the bottle, clean it well and fill it with water. Find its weight W_3 . Now, $(W_2 - W_1)$ is the weight of the liquid filling the bottle and $(W_3 - W_1)$ is the weight of water filling the bottle. They represent the weights of equal volumes of the liquid and of water.

Enter the readings as follows :—

Wt. of specific gravity bottle $= W_1$ grams.

Wt. of specific gravity bottle + liquid $= W_2$ grams.

Wt. of specific gravity bottle + water $= W_3$ grams.

$$\therefore \text{Specific gravity of liquid} = \frac{(W_2 - W_1)}{(W_3 - W_1)}$$

(2) **Specific gravity of an insoluble solid**—(Lead shot, pieces of iron wire or any insoluble powder).

Find the weight (W_1) of the clean, dry specific gravity bottle. Introduce the solid into the bottle and find the weight (W_2). $(W_2 - W_1)$ is the weight of the solid in air. Fill the bottle completely with water, taking the usual precautions. Find the weight (W_3). $(W_3 - W_2)$ is the weight of water whose volume is equal to the difference between the volume of the bottle and the volume of the solid. Empty the bottle and fill it completely with water alone. Find its weight (W_4). $(W_4 - W_1)$ is the weight of water filling the bottle. Obviously, $(W_4 - W_1) - (W_3 - W_2)$ is the weight of an equal volume of water.

Enter the readings as follows :—

Wt. of Sp. Gr. bottle = W_1 grams.

Wt. of Sp. Gr. bottle + solid = W_2 grams.

Wt. of Sp. Gr. bottle + solid + water = W_3 grams.

Wt. of Sp. Gr. bottle + water = W_4 grams.

$\therefore$ Weight of solid in air = $(W_2 - W_1)$

Weight of an equal }
volume of water } = $(W_4 - W_1) - (W_3 - W_2)$

$\therefore$ Specific gravity }
of solid } = $\frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)}$

[Note.—By following the method given below, one of the weighings can be avoided. It can be adopted, if there is no objection to placing the solid on the pan. Place the solid on the left hand pan and find its weight (W_1). Fill the specific gravity bottle with water, keep it by the side of solid on the pan and find the weight (W_2). Take out the bottle, carefully introduce the solid into it, insert the stopper and find the weight (W_3) now. The solid will displace an equal volume of water and it is clear that (W_3) will be less than (W_2), by the weight of an equal volume of water.

$$\text{Specific gravity of solid} = \frac{W_1}{(W_2 - W_3)} \cdot \quad]$$

(3) Specific gravity of a soluble solid

(Fragments of a soluble solid or soluble powder).

Find the weight (W_1) of the clean, dry specific gravity bottle. Introduce the solid into the bottle and find the weight (W_2). Fill it completely with a liquid in which the solid does not dissolve. Find the weight (W_3). Empty the bottle, fill it completely with the liquid alone and find the weight (W_4). Empty it again, wash it well and fill it completely with water. Find the weight (W_5).

Enter the readings as follows :—

Wt. of Sp. Gr. bottle = W_1 grams.

Wt. of Sp. Gr. bottle + soluble solid = W_2 grams.

Wt. of Sp. Gr. bottle + solid + liquid = W_3 grams.

Wt. of Sp. Gr. bottle + liquid = W_4 grams.

Wt. of Sp. Gr. bottle + water = W_5 grams.

∴ Weight of solid in air = $(W_2 - W_1)$.

Weight of an equal }
volume of liquid } = $(W_4 - W_1) - (W_3 - W_2)$

∴ Relative density of }
solid with respect }
to the liquid } = $\frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)}$.

Specific gravity of }
liquid } = $\frac{(W_4 - W_1)}{(W_5 - W_1)}$.

∴ Specific gravity of solid } = Specific gravity of liquid } × Relative density of solid with respect to the liquid }
= $\frac{(W_4 - W_1)}{(W_5 - W_1)} \times \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)}$

Note.—All the weights must be determined correct to three places of decimals.

EXPERIMENT 11

HYDROMETERS

Aim :—To determine Specific Gravities using (a) a Nicholson's Hydrometer and (b) a Common Hydrometer.

Apparatus :—Nicholson's Hydrometer, Common Hydrometer, two tall jars, small solids, any solution or liquid whose specific gravity is required, a box of weights.

(A) Nicholson's Hydrometer

Description :—The Nicholson's Hydrometer is a "constant immersion hydrometer." It consists of a long, hollow, cylinder of nickel-plated brass, ending in cones. A long, narrow stem is attached to the top cone. It carries a circular disc on which small weights and bodies can be placed. To the bottom cone is attached by means of a stirrup a hollow, conical bucket carrying lead shot. The weight of the lead shot in it is such that the hydrometer can float vertically in water or any liquid, immersed up to the bottom of the narrow stem.

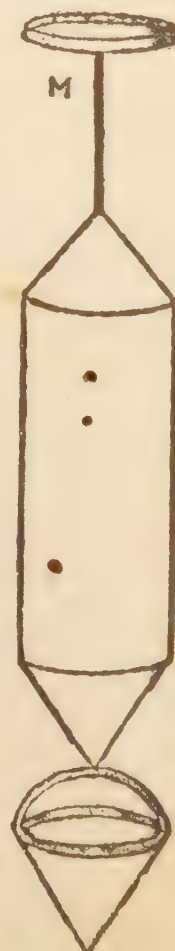


Fig. 22

Procedure :—Specific gravity of a liquid :—Find the weight (W) of the clean hydrometer. Float it vertically in a jar of water, without its touching the sides of the jar. Remove carefully all the air-bubbles sticking to the surface of the hydrometer. Cover the mouth of the jar with a slotted disc which, while allowing the hydrometer to freely move up and down, will prevent undesirable immersion of the jar. Add small weights to the top pan till the hydrometer sinks up to a fixed mark M on the stem, a little below the top pan. Note the weights (W_1) added. Remove the weights and the hydrometer. Carefully dry the hydrometer and float it in the liquid, taking the same precautions as before. Add weights (W_2) to the top pan, till the hydrometer sinks up to the same mark, in the liquid. Since the hydrometer sinks up to the same mark in both liquid and water, equal volumes of liquid and water are displaced. The weight of a floating body is equal to the weight of the displaced liquid. Hence,

$$\begin{aligned} \text{Specific gravity of } \left. \begin{array}{l} \text{the liquid} \end{array} \right\} &= \frac{\text{wt. of the displaced liquid}}{\text{wt. of an equal volume of displaced water}} \\ &= \frac{\text{wt. of hydrometer} + W_2}{\text{wt. of hydrometer} + W_1} = \frac{W + W_2}{W + W_1} \end{aligned}$$

Specific gravities of small solids :—The specific gravities of small solids can be determined using the hydrometer. Float the hydrometer in water, taking the usual precautions. Place the small solid on the top pan. Its weight must be such that the hydrometer does not sink up to the mark. Add weights, till the hydrometer sinks up to the mark. Remove the solid and place it on the bottom pan (top surface, of the conical bucket). Again add weights on the top pan till the hydrometer sinks up to the same mark. Let W_1 be the weight required to sink the hydrometer upto the mark in water, W_3 the weight required when the solid is on the top pan and W_4 , when it is on the bottom pan. Then, it is clear that $(W_1 - W_3)$ is the weight of the body in air and $(W_1 - W_4)$ is the weight of the body, in water. So,

$$\begin{aligned} \text{Specific gravity of the solid} &= \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}} \\ &= \frac{W_1 - W_3}{(W_1 - W_3) - (W_1 - W_4)} = \frac{W_1 - W_3}{W_4 - W_3} \end{aligned}$$

Determine the specific gravities of a few, more small solids. If the solid is a light substance like cork, then, while finding its weight in water, tie it to the lower pan with a piece of thread.

Tabulate the results thus :—

Solid	Weight required to sink up to mark in water W_1	Weight required with solid in upper pan W_3	Weight required with solid in lower pan W_4	Weight of body in air $(W_1 - W_3)$	Weight of body in water $(W_1 - W_4)$	Sp. Gr. $= \frac{(W_1 - W_3)}{(W_1 - W_4)}$
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(B) Common Hydrometer

Description :—The Common Hydrometer is a “constant weight hydrometer”. It consists of a hollow, cylindrical body of glass with a long, narrow stem at its top. It ends in a spherical bulb at the bottom. The bulb is loaded with mercury or lead shot, to make the hydrometer float vertically in a liquid, with part or whole of the stem above the surface of the liquid. The stem is usually graduated. To find the specific gravity of a liquid, the hydrometer is floated in it. The reading on the stem, up to which the hydrometer sinks gives directly the specific gravity of the liquid. The reading at the top of the stem corresponds to the lowest specific gravity and the reading at the bottom, to the highest specific gravity that could be determined with the given hydrometer. For different ranges, different hydrometers have to be constructed.



Fig. 23

A hydrometer with an ungraduated stem can be graduated as follows :—

Let a point near the top of the stem correspond to a known specific gravity s_1 and a point near the bottom, to a known specific gravity s_2 . Let l be the length of the stem between the marks, V the volume of the lower portion of the hydrometer up to the lower mark. Let “ a ” be the uniform area of cross section of the stem. Then

$$V \times s_2 = (V + l a) s_1 \quad \dots (i)$$

$$\therefore l a = \frac{V (s_2 - s_1)}{s_1}$$

If l_x is the length corresponding to an intermediate specific gravity s_x , then,

$$\begin{aligned} (V \times s_2 &= (V + l_x a) s_x) \\ \therefore l_x a &= -\frac{V (s_2 - s_x)}{s_x} \quad \dots (ii) \\ \therefore \frac{l_x a}{l a} &= \frac{V (s_2 - s_x)}{s_x} \div \frac{V (s_2 - s_1)}{s_1} \\ \therefore l_x &= \frac{l \times s_1 \times (s_2 - s_x)}{s_x (s_2 - s_1)} \end{aligned}$$

Knowing l , s_1 , s_2 and s_x , l_x corresponding to s_x can be calculated.

Float the hydrometer in a liquid of known specific gravity s_1 , which is such that the hydrometer floats up to a mark near the top of the stem. Mark the point. Float it next in a liquid of such a specific gravity (known) s_2 that it floats up to a mark near the bottom. Mark the point. Measure the distance l between the two marks. Using the formula given above, calibrate the stem for specific gravities lying between s_1 and s_2 .

EXPERIMENT 12

FORTIN'S BAROMETER—BOYLE'S LAW

Aim :—(a) To read the Atmospheric Pressure with a Fortin's Barometer and standardise it; (b) To verify Boyle's Law.

Apparatus required :—Fortin's Barometer, Boyle's Law Apparatus, Quill tube with a thread of mercury enclosing a column of dry air in it.

(A) Fortin's Barometer

Description :—The main feature of the Fortin's Barometer is the arrangement incorporated in it for keeping the level of mercury in the reservoir, constant, so that, the fluctuations of the mercury level due to changes of atmospheric pressure may not affect the reading. The reservoir is a cistern of glass, with a bottom made of thick chamois leather, which can be raised or lowered by a plunger under it, worked by a screw S at the bottom. The lower portion of the glass cistern is protected by a brass case, while through the upper portion, the mercury level inside can be seen. The barometer tube above is surrounded by a brass jacket

for protection and for carrying a fixed scale. The bottom of the brass jacket acts as a lid for covering the cistern. To the lid is fixed an inverted ivory index which projects into the cistern. The tip of the ivory index coincides with the zero of the scale marked on the instrument at the top, for measurement of atmospheric pressure. Hence, when the level of the mercury just touches the tip of the ivory index, it coincides with the zero of the scale. The brass jacket has openings at the top, in front and behind, with a central slot through which the barometer tube is visible. Brass scales referred to already are provided on both sides of the slot, on one of which inches and its subdivisions are marked and on the other, cms. and mms. A vernier bit on which verniers to suit the two scales are marked, slides up and down the slot, operated by a side screw in the brass jacket. The bottom of the vernier bit is the zero of the vernier. Behind the open slot at the top, a plane mirror or a milk white plate is fixed to the board on which the barometer is mounted. The image of the mercury level is seen in the mirror and helps to eliminate errors due to parallax. A thermometer T is fixed to the barometer case for measuring the temperature of the air at the time of reading the atmospheric pressure.

Procedure:—Read the temperature in the thermometer attached to the barometer. Find the least count of the verniers. Work the screw at the bottom of the barometer, so that the level of mercury in the cistern goes below the tip of the ivory index. Then, raise it gently till the tip of the index just touches the mercury surface. The image of the index in the mercury helps to make this adjustment correctly. This can be easily and accurately done, if the mercury surface is clear and free from dirt. Then, working the side screw which operates the vernier bit, raise it above the level of the mercury in the tube. Gradually lower it till the lower edge of the vernier is in the



Fig. 24 . .

horizontal plane passing through the top of the convex surface of the mercury. With the help of the image of the surface seen in the plane mirror, this can be done accurately without parallax error. Read the vernier. The main scale reading plus the reading of the coinciding division on the vernier gives the atmospheric pressure.

To standardise the above reading, to give the correct atmospheric pressure, corrections have to be applied for (1) expansion of mercury and of the brass scale due to temperature, (2) capillarity (3) index error and (4) changes in the value of “g” due to latitude and altitude. But, for all practical purposes, the corrections due to temperature alone are applied as the others are more or less negligible.

If t is the room temperature, t_1 the temperature at which the scale has been marked, “ a ” the co-efficient of linear expansion of the material of the scale, “ b ” the co-efficient of volume expansion of mercury, H_t the reading taken at room temperature t , then H_0 the standardised atmospheric pressure is given by,

$$H_0 = H_t \left\{ 1 - at + b(t - t_1) \right\}$$

For mercury, $a = 0.0001819$

For brass, $b = 0.0000184$

$$\therefore H_0 = H_t \left\{ 1 - 0.0001819 t + 0.0000184 (t - t_1) \right\}$$

Read the atmospheric pressure and standardise it.

(B) Boyle's Law

Aim :—To verify Boyle's Law by using (1) the Boyle's Law apparatus and (2) the Quill tube.

Apparatus required :—Boyle's Law apparatus, Quill tube.

(1) Boyle's Law apparatus

Description :—A cylindrical glass tube T closed at the top and a similar glass tube R open at both ends are connected together by a thick walled rubber tube and mounted on a tall vertical wooden stand. In between the two tubes is fixed a meter scale, graduated in cms. and mms. on both sides. The closed tube is fixed at the middle while the open tube can be moved up and down and fixed in any position with a clamp on a metallic rod at the side.

Clean, dry mercury fills about half of the closed tube, the rubber tube and about half of the open tube, when the two are fixed at the same level. Above the mercury in the closed tube is enclosed a certain mass of dry air while the mercury in the open tube is exposed to the atmosphere.

Procedure:—Read the atmospheric pressure from a Fortin's Barometer and standardise it. Adjust the movable tube till the mercury levels in both the tubes are in the same horizontal line. The pressure of the air in the closed tube is equal to the atmospheric pressure. Note the readings on the scale, of the top of the closed tube and of the mercury level in it. The difference gives the length of the air column which is proportional to its volume, as the cross-section of the tube is uniform. Now, raise the movable tube so that the difference in the mercury levels is about 10 cms. Note the readings on the scale, of the two mercury levels. The pressure of the air inside the closed tube is equal to the atmospheric pressure plus the difference in the mercury levels. Raise the movable tube so that the difference in the mercury levels is 20 cms., 30 cms., etc. and read the difference in the levels in each case. Then, lower the tube so that the mercury level in it is below the other by 10 cms. 20 cms., 30 cms., etc. The pressure of the enclosed air is now equal to the difference between the atmospheric pressure and the difference in level between the two. Tabulate the readings as follows:—

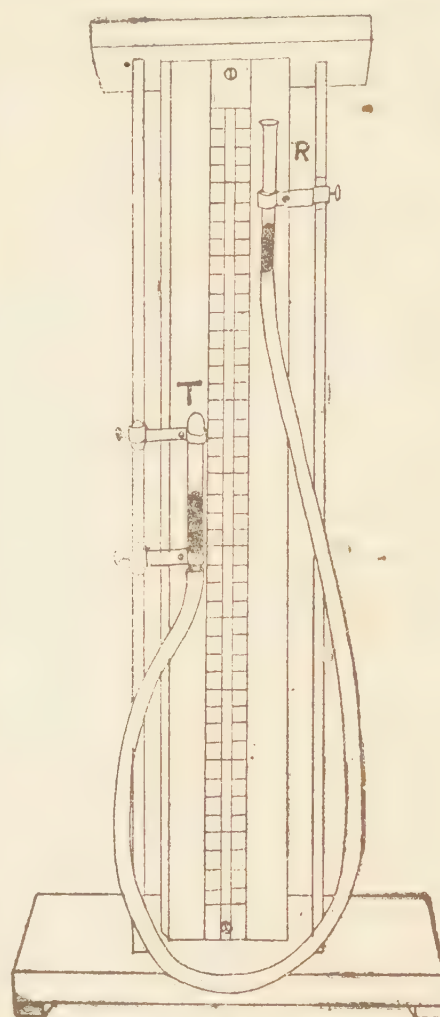


Fig. 25

Reading of mercury in closed tube a	Reading of top of closed tube b	Length of enclosed air column $b-a$ (l)	Reading of mercury in open tube c	Difference in mercury levels $a - c$ (p)	Atmospheric pressure P	Total pressure $P + p$	Total pressure $\times$ length $(P + p)l$
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The values in the last column will be constant.

Graph :—Plot the length (proportional to volume) of air column on the X axis and its pressure on the Y axis. The shape of the curve will be a rectangular hyperbola.

(2) The Quill tube

Description :—The quill tube is a long glass tube AB with a narrow, uniform cross-section (say about 0.25 cms.), and about a metre in length. Hot, dry air is passed through it. A thread of clean, dry mercury about 20 cms. long is drawn into it and one end A of the tube carefully sealed, so that the mercury thread encloses a column of dry air about 25 cms. long between it and the closed end. It is then tied to a metre scale.

Procedure :—The quill tube is clamped horizontally. The pressure of the enclosed air is then equal to the atmospheric

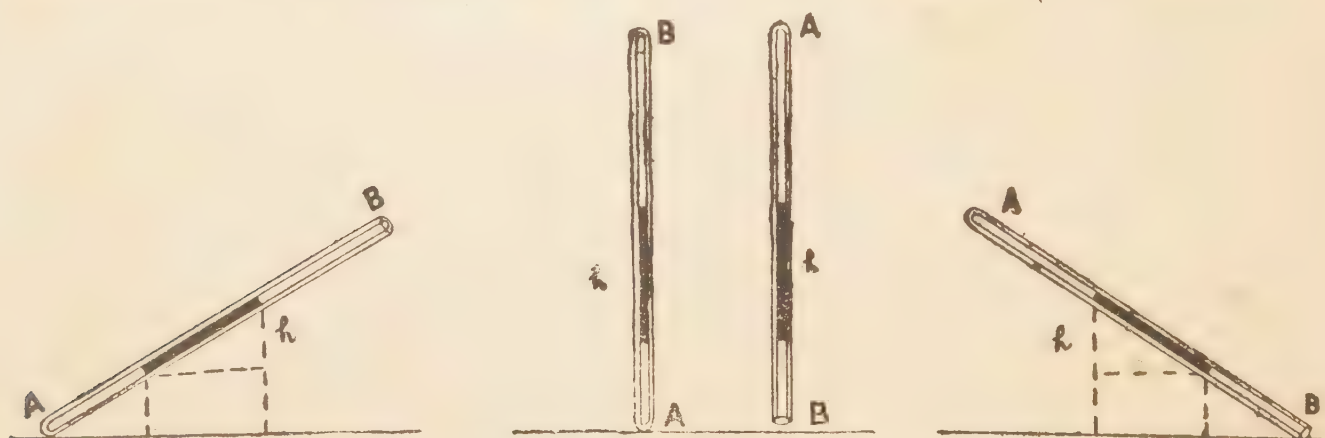


Fig. 26

pressure. The length of the air column is measured on the attached scale. It is proportional to the volume as the tube is uniform in cross-section. The quill tube is then gently rotated and clamped in a slanting position, with its open end B up. The pressure of the air inside increases and is equal to the atmospheric pressure plus the difference in vertical height h between the ends of the mercury thread. This is obtained by measuring the vertical heights of the two ends of the mercury thread from the surface of the table and finding their difference. The length of the enclosed air column is noted. After taking three or four readings with the open end up, the quill tube is gently rotated so that the open end is below the level of the closed tube. The pressure of the enclosed air is now less than the atmospheric pressure and is equal to the atmospheric pressure minus the difference in vertical height

between the ends of the mercury thread. This difference in vertical height is measured as before. The length of the enclosed air column is measured. Three or four readings are taken keeping the open end below the level of the closed tube. The lengths of the air column and the corresponding pressures are thus known. The readings are tabulated as follows:—

Position of quill tube	Length of air column l	Vertical Height of mercury thread			Atmospheric Pressure P	Total Pressure $P \pm h$	Pressure $\times$ Length (volume) $(P \pm h) l$
		Height of one end from table	Height of the other end from table	Difference in height h			

The values in the last column will be constant.

Graph :—Plot a graph, representing the lengths of the air column (proportional to volume) along the X axis and the corresponding pressures on the Y axis. The curve will be a rectangular hyperbola.

SECTION II

GENERAL PHYSICS

EXPERIMENT 13

SURFACE TENSION BY DROPS

Aim :—To determine by the method of drops (1) the surface tension of a liquid and (2) the interfacial surface tension of two immiscible liquids.

Apparatus required :—Burette, two glass tubes of 3 to 5 mm. bore, two or three small beakers, Vernier Microscope, Hare's apparatus.

(1) Surface Tension of a liquid

Procedure :—Mount a clean burette vertically in a burette stand. Attach a short length of rubber tubing to its lower end. Insert the given glass tube into the rubber tube and adjust it so that its mouth is horizontal. The glass tube must first be cleaned

thoroughly with caustic soda solution to remove traces of grease.

It is then washed in water and rinsed with dilute nitric acid. Finally wash it well with tap water. If the burette has no stop-cock, attach a pinch clamp to the rubber tube. The stop-cock is closed. The liquid whose surface tension is required, say water, is poured into the burette. A beaker is placed under the burette. The stop-cock is opened slowly so that the liquid passes to the tube below and leaves it drop by drop. Adjust the flow so that the drops form slowly and fall down, at the rate of about 20 to 30 per minute. Weigh a small, clean, dry beaker correct to three places of decimals. Place it under the tube and collect about 100 to 150 drops. Find the weight again accurately and calculate the weight of each drop.



Fig. 27

Repeat three or four times and find the mean weight of a drop. Close the stop-cock. Remove the tube. Mount it horizontally on a stand. With the vernier microscope, find its external diameter, horizontal as well as vertical. Find their mean and calculate the radius.

Dip the end of the other tube in molten paraffin. Allow it to cool and scrape off excess paraffin, if any. The liquid will not wet paraffined glass and in this case, the drops will form from the inner edge. Perform the experiment as before and find the mean weight of a drop. With the microscope, measure the internal diameter in two perpendicular directions and find their mean. Calculate the radius.

To find the surface tension of any other liquid, remove the water, allow some of the liquid to run through the apparatus to remove traces of water. Pour the liquid in the burette and repeat the experiment as before.



Fig. 28

Calculations :—If the drop is formed slowly, it assumes a cylindrical shape before it breaks away. The diameter of the cylinder is equal to the diameter of the tube. Then, it can be shown that the weight of the drop $mg = \pi rT$ where T is the surface tension and r the radius of the tube.

$$\therefore T = \frac{mg}{\pi r}$$

[The value of π , however, has to be assumed to be 3.8 and not 3.1416. This is known as Rayleigh's correction.]

Tabulate the results as follows :—

I. Clean tube. Liquid used is

Trial No.	No. of drops collected (n)	Weight of			Weight of each drop
		Beaker	Beaker + drops	n drops alone	

$\therefore$ Mean weight of a drop = m_1 gms.

II. Paraffined tube. Liquid used is

Trial No.	No. of drops collected (n)	Weight of			Weight of each drop
		Beaker	Beaker + drops	n drops alone	

$\therefore$ Mean weight of a drop = m_2 grams.

Mean external diameter of clean tube = r_1 cms.

Mean internal diameter of paraffined tube = r_2 cms.

$$\therefore T = \frac{m_1 g}{3.8 r_1} \quad \text{or} \quad \frac{m_2 g}{3.8 r_2}$$

(2) Interfacial Surface Tension

Procedure :—Pour the heavier liquid into the burette and the lighter liquid into a clean beaker. Use the clean glass tube. Determine accurately the weight of the beaker and liquid. Place the beaker under the burette and introduce the tube into the liquid in the beaker. Open the stop-cock of the burette partially, till drops form slowly and sink into the liquid in the beaker. After collecting 50 to 100 drops, remove it and find the weight. From this, find the total weight of the drops and calculate the weight of each drop. Repeat the experiment using another weighed beaker. Calculate the weight of each drop formed in the liquid in the beaker.

With a Hare's apparatus, find the relative density of the two liquids. Half a dozen different heights must be taken and the mean relative density determined.

Due to buoyancy, the upward thrust on each drop formed inside the liquid will be $\frac{mg}{d_1} \times d_2$ where d_1 is the density of the heavier liquid in the burette and d_2 , the density of the lighter liquid in the beaker. So, the apparent weight of the drop will be

$$mg - \frac{mg d_2}{d_1} \text{ or } mg \left\{ 1 - \frac{d_2}{d_1} \right\}$$

$$\therefore T = \frac{mg}{3.8 r} \left\{ 1 - \frac{d_2}{d_1} \right\}.$$

Where $\frac{d_2}{d_1}$ is the relative density of the lighter liquid with reference to the heavier and r is the external radius of the tube.

Tabulate the results as follows :—

I. Mean weight of a drop.

Trial No.	No. of drops collected (n)	Weight of beaker + lighter liquid	Weight of beaker + lighter liquid + drops	Weight of n drops	Weight of each drop
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$\therefore$ Mean weight of a drop = m grams

Mean diameter of the tube = r cms.

II. Relative density—Hare's apparatus :—

Trial No.	Height of heavier liquid h_1	Height of lighter liquid h_2	Relative density $\frac{d_2}{d_1} = \frac{h_1}{h_2}$
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Mean relative density of lighter liquid with reference to heavier liquid $\left(\frac{d_2}{d_1} \right)$ } =

$$\therefore T = \frac{mg}{3.8 r} \left(1 - \frac{d_2}{d_1} \right).$$

EXPERIMENT 14

SURFACE TENSION OF A LIQUID BY
CAPILLARY RISE

Aim:—To determine the surface tension of a liquid by capillary rise.

Apparatus required:—Vernier Microscope, capillary tubes, drawn out tubes, water or liquid.

Procedure:—The tubes used for surface tension experiments must be perfectly clean. Any contamination, particularly grease, will considerably alter the surface tension. So, clean the tubes first with caustic soda solution. Wash with tap water and then rinse them with nitric acid. Give a final wash with tap water. Tap water or well water is free from oil or grease.

Take a two holed rubber stopper. Pass the capillary tube C through one of the holes and a long knitting needle P with a pointed end through the other. The holes must be of such a size that the tube and the needle fit into them. Fix the rubber stopper in a retort clamp so that the tube and the needle are side by side and vertical. This may be tested by a plumb-line.

Place a beaker of water or the liquid under the capillary tube. Raise it so that about two or three cms. of the tube are under the liquid. A short length of rubber tubing R is attached to the top of the tube. When this is pressed and released repeatedly, the liquid that rises into the tube wets the tube and will be free from tiny air bubbles. Adjust the needle so that its end just touches the surface of the liquid in the beaker. This adjustment must be made with care.

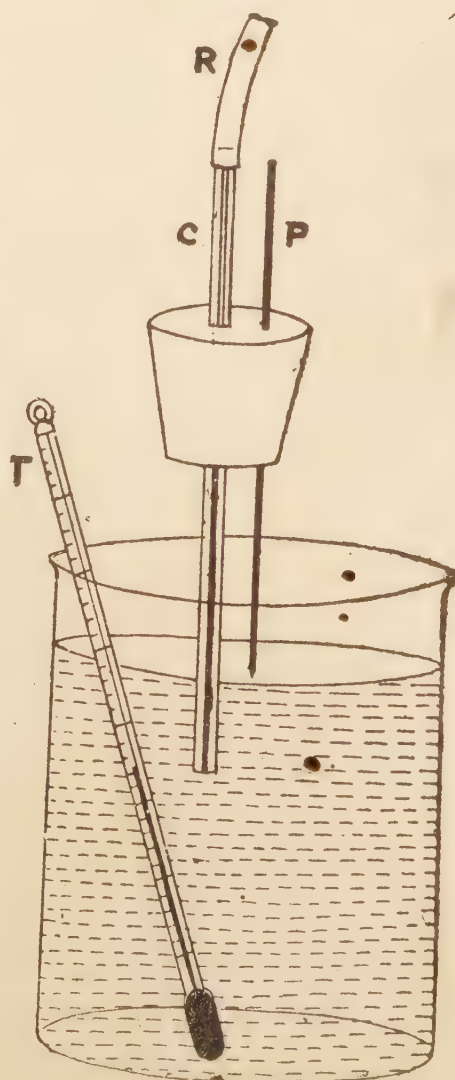


Fig. 29

Set up the vernier microscope in front of the capillary tube. Turn the microscope so that its axis is horizontal and passes through the centre of the capillary tube. Adjust the eye-piece so that the cross-wires in it are seen distinctly. Focus the microscope on the tube. Raise or lower it till the level of the liquid in the tube is in the field of view. Adjust the microscope so that the liquid meniscus is in clear focus. Raise or lower it carefully so that the horizontal cross-wire is tangential to the bottom of the meniscus. (If the liquid wets the glass, the liquid surface in the tube will be concave. The inverted image of it seen in the field of view will be convex). Take the reading on the vertical scale of the microscope by noting the readings on the main scale and the vernier scale. By pinching the rubber tube at the top or by raising the beaker of liquid a little and lowering it, disturb the level of the meniscus. Adjust again so that the horizontal cross-wire is tangential to the top of the meniscus and take the reading. Repeat a number of times. Introduce a thermometer into the liquid and measure its temperature. Gently lower the beaker of liquid and remove it. Lower the microscope and adjust it so that the cross-wire coincides with the tip of the needle. This represents the level of the liquid in the beaker. Take the reading. The difference between this reading and the mean reading taken of the meniscus will give the height of the liquid risen in the tube. Repeat the experiment twice or thrice.

If the capillary tube used is uniform, you may find its radius using the vernier microscope or a mercury thread. Hold the tube in a horizontal position. Focus the microscope on the end of the tube. Measure the horizontal and the vertical diameters and calculate the mean diameter and radius.

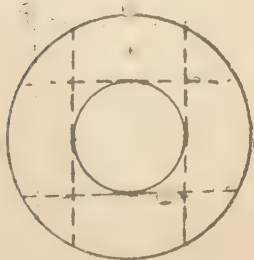


Fig. 30

If a drawn out capillary tube is used, its cross-section will not be uniform. The radius at the place where the meniscus stood has to be measured. So, this place is carefully noted. The tube is removed. Make a fine file mark at the place and gently break it there so that a circular section is obtained. Measure the mean diameter of this circular opening, with a vernier microscope and calculate the radius.

Find the specific gravity of the liquid, if it is other than water, using the Hare's apparatus. Take half a dozen readings for different heights of the liquid and water. Note also the temperature of the liquid.

Calculations :—Let h be the height of the liquid in the tube above the level of the liquid in the beaker, due to capillary rise, Let r be the radius of the tube, d density of the liquid and T the surface tension of the liquid. Then,

$$T = \frac{r\rho g}{2} \left\{ h + \frac{r}{3} \right\}.$$

$$\left[\frac{r}{3} \text{ is the correction for the meniscus.} \right]$$

Tabulate the readings as follows :—

The liquid used was water at 29°C.

I. Height of the liquid in the capillary tube—

Least count of the microscope = 0.001 cm.

Trial No.	Reading of bottom of meniscus	Reading of tip of needle	Difference in height
1	7.818 cms.	1.587 cms.	6.231 cms.
2	7.817 „		6.230 „
3	7.822 „		6.235 „
4	7.852 „	1.571 „	6.281 „
5	7.845 „		6.274 „
6	7.838 „		6.267 „
7	7.809 „	1.566 „	6.243 „
8	7.811 „		6.245 „
9	7.810 „		6.244 „
Mean			6.250 „

∴ Mean capillary rise = 6.250 cms.

II. Radius of Capillary tube—

It was measured¹ using a mercury thread.

Average length of mercury thread = 5.032 cms.

Weight of mercury = 0.115 gms.

$$\therefore \text{Radius } r = \sqrt{\frac{0.115}{3.1416 \times 5.032 \times 13.59}}$$

$$= 0.023 \text{ cms.}$$

$$\therefore T = \frac{0.023 \times 1 \times 980}{2} \times \left\{ 6.250 + \frac{0.023}{3} \right\}$$

$$= \frac{0.023 \times 980 \times 6.258}{2}$$

$$= 70.7 \text{ dynes per cm.}$$

$\therefore$ The surface tension of water }
by capillary rise at 29° C. } = 70.7 dynes per cm.

EXPERIMENT 15

SURFACE TENSION OF A LIQUID BY SEARLE'S TORSION BALANCE

Aim :—To determine the Surface Tension of a liquid by Wilhelmy's method using Searle's Torsion Balance.

Apparatus required :—Searle's Torsion Balance, glass basin, thin rectangular glass plates (microscope slides), weight box.

Description of Apparatus :—The Searle's Torsion Balance for determining surface tension consists of a heavy tripod stand with a hole at its centre. A sliding vertical rod carrying at its top a bracket is inserted in this hole. By a side screw, the rod can be clamped in any position. Stretched tightly across the bracket, is a steel wire about 20 cms. long. The ends of the wire are passed into holes in the arms of the bracket and

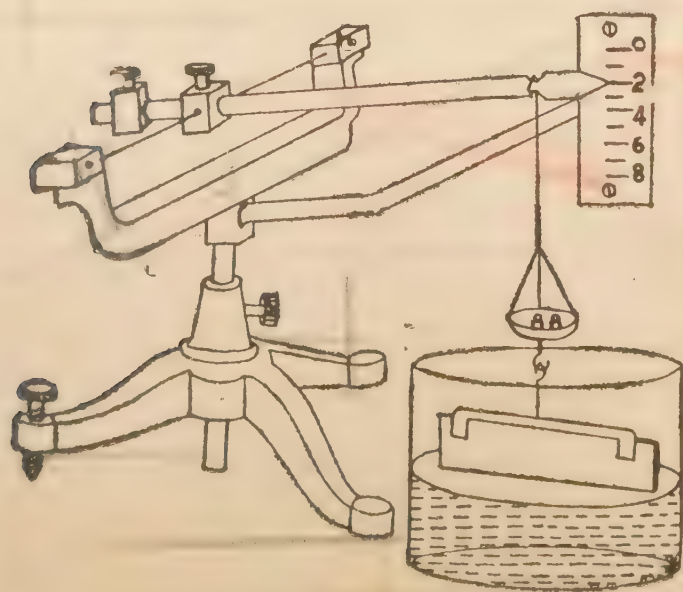


Fig. 31

held firmly by means of screws. At the centre of the wire, there is a nut which slides over it and can be clamped in any position with a screw. It carries on one side of it a long, flat pointer which tapers at its end. The end of the pointer moves over a vertical scale. About one cm. from the end of the pointer, a scale pan is hung. The scale pan has a hook at its bottom. On the other side of the nut, there is a short arm which carries a sliding weight which can be fixed at any position. One leg of the tripod has a levelling screw, by adjusting which, that leg can be raised or lowered.

Procedure :—Rotate the bracket, so that the short arm with the sliding weight is vertically above the leg with the levelling screw. Any vertical force applied to the pointer produces torsion in the stretched wire. When the force is removed, the restoring torsional couple brings it back to its equilibrium position.

Clean the glass plate thoroughly so as to be free from grease and dirt. Insert it into a special double clip and hang it from the hook at the bottom of the scale pan. The lower edge of the plate must be horizontal. So, adjust the position of the sliding weight till the pointer is horizontal. Place the glass basin with the liquid (or water) under the plate, so that the plate hangs with its lower edge about $\frac{1}{2}$ a cm. or so above the level of the liquid in the basin. Adjust the levelling screw, so that, when the glass plate is gently pushed down so as to touch the surface of the liquid, it is just held down by the liquid due to the force of surface tension. This has to be done carefully, as it is a delicate adjustment. Note the readings on the scale opposite to the pointer (1) when it is in the equilibrium position and (2) when the glass plate is touching the surface of the liquid. Disturb the arrangement and take another reading. Repeat and take a number of readings, not less than half a dozen, at any rate. Remove the basin with the liquid. Allow the pointer to take up its position of rest. Add small weights to the pan so that the pointer moves down by just the distance through which it moved for the glass plate to touch the surface of the liquid. Obviously, this weight is equal to the force acting on the plate due to surface tension.

EXPERIMENT 16

SURFACE TENSION OF LIQUID BY QUINCKE'S
DROP METHOD

Aim :—To determine the Surface Tension of a liquid by Quincke's drop method.

Apparatus required :—A clean glass plate, clean dry mercury, Vernier Microscope.

Procedure :—The method is usually used for determining the surface tension of mercury which easily forms a large drop on the clean surface of a glass plate which it does not wet. [It can also be used for water, by forming a fairly large drop of it on a paraffined glass plate which it does not wet.]

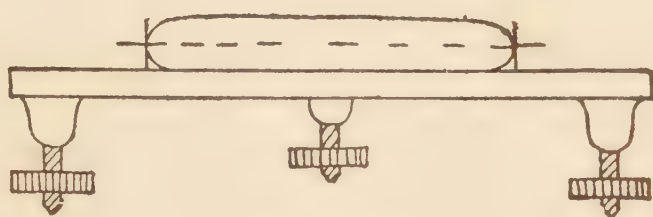


Fig. 32

Place the clean glass plate on a levelling table provided with three levelling screws. Using a spirit level, adjust the screw so that the top of the table is perfectly horizontal. Form a large drop of dry, pure mercury at the centre of the glass plate. The top surface of the drop will be flat and horizontal.

Set up the vernier microscope in front of the drop. Turn the microscope so that its axis is horizontal. Adjust the eye-piece so that the cross-wires are distinctly seen, one of them being horizontal and the other vertical. [Test whether it is vertical by focussing the microscope on a plumb-line.]

Focus the microscope on the mercury drop. Move the microscope, laterally, so that the edge of the drop is in the field of view. Adjust so that the vertical cross-wire is tangential to the convex edge of the drop and the point of intersection of the cross-wires coincides with the turning point of the convex bulge. The reading on the vertical scale is taken. Raise the microscope so that the top of the drop is in focus. A few particles of lycopodium strewn on the drop will facilitate this. When

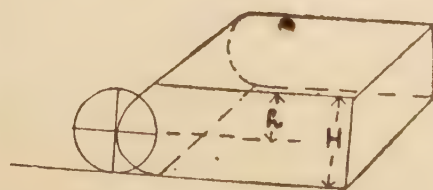


Fig. 33

the horizontal cross-wire is flush with the top surface of the drop, take the reading. Lower the microscope so that the surface of the glass plate i.e., the bottom surface of the drop is in focus. Make the horizontal cross-wire coincide with this surface and take the reading.

Repeat the manipulations and take a number of readings.

Calculations :—The difference in reading between the top and the bottom of the drop gives H , the height of the drop. Let the difference in reading between the top of the drop and the turning point be h . Then, it can be shown that the surface tension is given by,

$$T = \frac{g \rho h^2}{2}.$$

$$\text{and } \sin \frac{\theta}{2} = \frac{H}{\sqrt{2} \times h}.$$

where ρ is the density of the drop and θ is the angle of contact of mercury with the glass surface.

Tabulate the results as follows :—

Trial No.	Reading of turning point	Reading of top of drop.	Reading of bottom of drop.	h .	H .
	1.	2.	3.	(2 — 1)	(2 — 3)

From the mean values of h and H , calculate T and θ .

Perform the experiment by forming (1) a large drop of pure mercury on a clean glass plate and (2) a large drop of water on a paraffined glass plate.

EXPERIMENT 17

COEFFICIENT OF VISCOSITY OF A LIQUID BY POISEULLE'S FLOW

Aim :—To determine the coefficient of viscosity of a liquid by Poiseulle's flow, using a capillary tube.

Apparatus required :—An aspirator, burette, capillary tubes, liquid, Hare's apparatus, stop-clock or stop-watch.

(A) Using an Aspirator

Setting up a suitable pressure head is an important part of the experiment. An aspirator of 2 or 3 litres capacity can be used. The outlet at the bottom is closed by an one-holed rubber stopper. Through this hole a short glass tube is inserted and a short length of rubber tubing attached to it. The capillary tube C is introduced into the rubber tubing and kept in a horizontal position. A pinch-cock is fitted to the rubber tube and is used for allowing the flow whenever required.

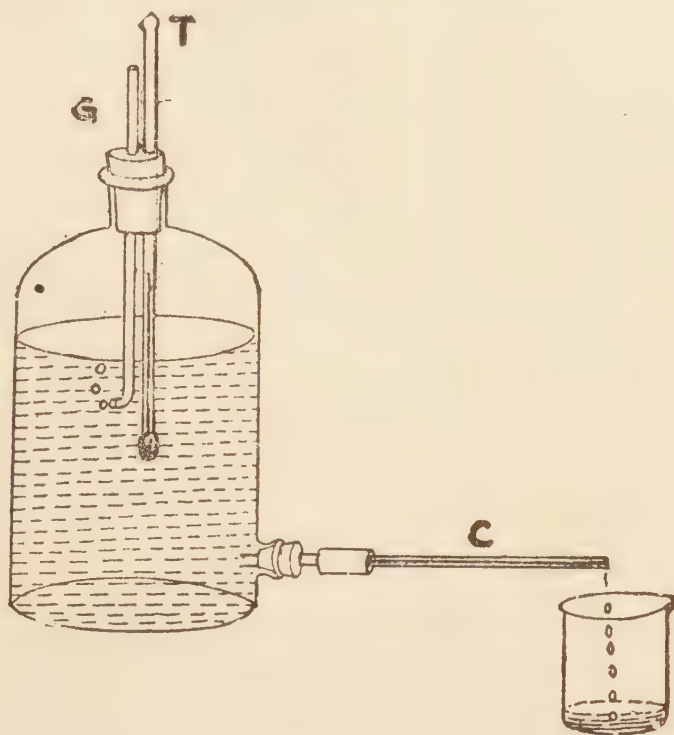


Fig. 34

Close the rubber tube with the pinch-cock. Pour the liquid into the aspirator to about $\frac{3}{4}$ of its volume. As the volume of water flowing through the capillary tube is usually small, the difference between the initial and final levels in the aspirator will not be much. The average level can be noted and used. A long strip of cm. graph paper pasted vertically on the side of the aspirator will serve to note the levels of the liquid.

[A constant pressure-head can, however, be set up as follows. Close the mouth of the aspirator with a tight fitting one-holed rubber stopper. Insert a long glass tube G with a narrow bore into it and push it down so that its lower end is a few cms. below the level of the liquid. The lower end of the tube is bent at right angles to the tube. The mouth of the tube inside the liquid is at atmospheric pressure and till the liquid reaches that level, the pressure-head will be constant.]

(B) Using a Burette

A simple arrangement, when the quantity of liquid available is limited, is to use a burette without a stop-cock. The burette is mounted vertically. A short length of rubber tubing is connected to the bottom of the burette. A capillary tube is inserted into

the rubber tube and kept in a horizontal position. A pinch-cock fitted to the rubber tube is used for stopping or for allowing the flow of liquid. The rubber tube is closed and the liquid is poured into the burette. A constant pressure-head is out of the question in this case. Since the burette has a small cross-section, there will be an appreciable difference in level as the liquid flows. But, with a graduated burette, the volume of liquid flown out can be read off directly from the burette.

Procedure :—At the outset, determine the radius of the dry capillary tube. A long mercury thread, covering the major portion of the capillary tube, is drawn into it. Measure its length. Collect the mercury on a weighed watch glass and determine its weight accurately. From the length and weight of the mercury thread, calculate the radius. As the fourth power of the radius occurs in the formula, it has to be determined very accurately.

Clean the capillary tube so as to be free from grease and dirt. Wash it first with caustic soda solution, then with water and with nitric acid or chromic acid, and finally with tap water. Insert it into the rubber tubing. Open the pinch-cock *completely so that there is no restriction to the passage of the liquid through the rubber tube*. The liquid flows through the capillary tube and emerges from it drop by drop.

It is very important for the success of the experiment that the flow of the liquid in the capillary tube should be slow and streamlined. This is secured, if the flow of drops from the tube is slow and regular. A short length of thread tied at the free end of the tube and hanging from it, prevents the liquid from running along the tube and facilitates the regular formation and collection of drops. Or smear a little vaseline at the end of the tube.

Weigh a small beaker. When the flow is uniform, place the weighed beaker below the end of the tube and start a stop-clock or stop-watch. Note, simultaneously, the level of the liquid in the burette or aspirator. [If the arrangement for constant pressure head is made in the aspirator, this reading will be unnecessary.] Collect a fair quantity of the liquid, and note the time taken. Read the level of the liquid in the burette or aspirator. Weigh the beaker with the liquid and find the weight of liquid collected.

Repeat the experiment and take a number of readings. Measure the vertical height h_2 of the mouth of the capillary tube from the surface of the table. Find out also the vertical height h_1 of the mean level of the liquid in the burette or aspirator from the surface of the table in each case. The difference in vertical height between the mean level of the liquid in the burette or aspirator and mouth of the capillary tube is the pressure-head.

If the liquid used is other than water, find its specific gravity, using the Hare's apparatus. Take the mean of half a dozen readings.

Note the temperature of the liquid with a thermometer.

Calculations :—When a liquid flows through a capillary tube due to a constant pressure-head, the volume of liquid V flowing through it in an interval of time t seconds is given by,

$$\frac{V}{t} = \frac{\pi p r^4}{8 l \eta}$$

The pressure-head $p = (h_1 - h_2)$. Expressed in absolute units, it is $(h_1 - h_2) \rho g$ dynes where ρ is the density of the liquid. η is the coefficient of viscosity of the liquid. If Q is the quantity of liquid in grams collected in t seconds,

$$\begin{aligned} V &= \frac{Q}{\rho} \\ \therefore \frac{Q}{\rho} &= \frac{\pi (h_1 - h_2) \rho g r^4}{8 l \eta} \\ \therefore \eta &= \frac{\pi r^4 (h_1 - h_2) \rho^2 g t}{8 l Q} \end{aligned}$$

Tabulate the results as follows :—

Liquid used is water. So, density is 1. Aspirator is used for the pressure-head.

Radius of capillary tube :—

$$\left. \begin{array}{l} \text{Mean length of mercury thread} \\ \text{measured with a vernier} \\ \text{microscope.} \end{array} \right\} = 4.092 \text{ cms.}$$

$$\text{Weight of mercury} = 0.105 \text{ grams.}$$

$$\therefore r = \sqrt{\frac{0.105}{3.1416 \times 4.092 \times 13.6}} = 0.0245 \text{ cms.}$$

Weight of water collected } = 61.86 grams
in 25 minutes

Pressure-head = 28.7 cms.

Length of capillary tube = 10.56 cms

The temperature of water = 28.6° C

$$\therefore \eta = \frac{3.1416 \times 0.0245^4 \times 28.7 \times 980 \times 25 \times 60}{8 \times 10.56 \times 61.86}$$

$$= 0.00915 \text{ dynes per sq. cm.}$$

$\therefore$ The coefficient of viscosity of } = 0.00915 dynes
water at 28.6° C } per sq. cm.

Tabulate likewise the other readings taken.

EXPERIMENT 18

COMPARISON OF THE VISCOSITIES OF TWO LIQUIDS

Aim :—To compare the coefficients of viscosity of two liquids.

Apparatus required :—Ostwald's bulb, burette, capillary tube two liquids, Hare's apparatus, stop-clock or stop-watch.

(1) Ostwald's bulb

Description :—The Ostwald's bulb consists of a fine capillary tube bent into the form of a U with one arm longer than the other. At each end of the capillary tube, there is a spherical bulb. The bulb at the end of the longer arm has two fine file marks M_1 , M_2 above and below it. To its neck is connected a short length of rubber tubing, provided with a screw-clip to close or open it.

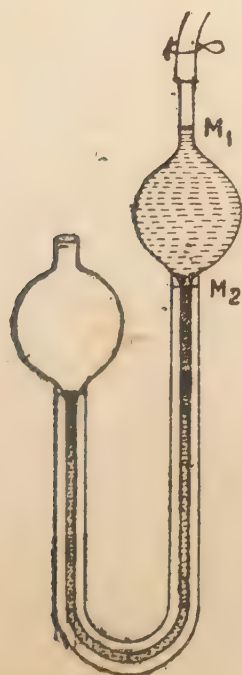


Fig. 35

Procedure :—Clean the apparatus thoroughly, to be free from grease, dirt, etc., and dry it. Mount it vertically. Introduce one of the liquids into the bulb at the end of the shorter limb. With the help of the rubber tube suck it up into the other bulb, so that the liquid comes up to the level of the file mark M_1 , above the bulb. Close the rubber tube tightly. Keep ready a stop-clock

or stop-watch. Open the rubber tube and start the stop-clock simultaneously. The liquid level falls down and it is forced through the capillary into the bulb on the other side. When the level falls to the lower file mark M_2 , stop the stop-clock and note the time. Suck up the liquid again and repeat the experiment. Note the mean time required for the liquid to fall from the upper mark to the lower.

Empty the liquid, clean the apparatus again and dry it. Mount it vertically. Introduce the other liquid into the apparatus and repeat the experiment. Note the mean time required for the liquid to fall from the higher level to the lower level.

Using the Hare's apparatus, determine their relative density. Take half a dozen readings and find their mean.

Calculations:—The volume of liquid flowing, the length and the radius of the capillary bore and the pressure-head are identical in the two cases. If t_1 and t_2 are the respective times of flow of the two liquids, ρ_1 and ρ_2 their densities and η_1 and η_2 their coefficients of viscosity, then,

$$\frac{V}{t_1} = \frac{\pi h \rho_1 r^4}{8 \eta_1} \quad \text{and} \quad \frac{V}{t_2} = \frac{\pi h \rho_2 r^4}{8 \eta_2}$$

$$\therefore \frac{\eta_1}{\eta_2} = \frac{t_1}{t_2} \times \frac{\rho_1}{\rho_2}$$

From this, the ratio of the coefficients of viscosity is calculated.

Tabulate the readings taken of the intervals of time and of the relative density.

(2) Burette

Procedure:—Mount the clean, dry burette vertically on a burette stand. A burette without a stop-cock at the bottom must be used. Attach a short length of rubber tubing at the lower end of the burette. A pinch-cock is attached to the rubber tube. Introduce a clean, dry capillary tube into the rubber tube and mount it horizontally. Pour one of the liquids into the burette. Open the pinch-cock *completely* and allow the liquid to flow through the capillary tube so that the formation of drops is slow and regular. This is secured by taking a long capillary tube of fine bore and having a low pressure-head. Keep a stop-clock or stop-watch ready. Start it when the level of the liquid reaches a

certain mark on the burette. Allow the liquid to flow and when the volume of liquid flown as indicated by the burette is 10 or 15 c.cs, stop the stop-clock and note the time. Fill the liquid upto the same level and repeat the experiment. Take four or five readings by changing the pressure-head each time. Remove the liquid from the burette. Clean the burette and the capillary tube thoroughly and set them up again. Pour the other liquid into the burette and repeat the experiment keeping the initial and final levels the same as for the first liquid. Take three or four readings

With the Hare’s apparatus, find the mean relative density of the liquids. Take half a dozen readings and find their average.

Calculations :—Let the initial and final levels of the liquids be the same in each case. So, the volume of liquid flown and the mean pressure-head remain the same. If t_1, t_2 be the times of flow for the respective liquids, ρ_1, ρ_2 their densities, and η_1, η_2 their coefficients of viscosity,

$$\frac{\eta_1}{\eta_2} = \frac{t_1}{t_2} \times \frac{\rho_1}{\rho_2}$$

Calculate the ratio.

I. Tabulate the readings as follows :—

Initial Reading of burette	Final Reading of burette	Time of flow							
		Liquid I				Liquid II			
		1	2	3	Mean t_1	1	2	3	Mean t_2

II. Hare’s Apparatus

Trial No.	Height of column of liquid I h_1	Height of column of liquid II h_2	$\frac{h_2}{h_1} = \frac{\rho_1}{\rho_2}$

Calculate the ratio $\frac{\eta_1}{\eta_2}$ from the mean values of t_1, t_2 and $\frac{\rho_1}{\rho_2}$.

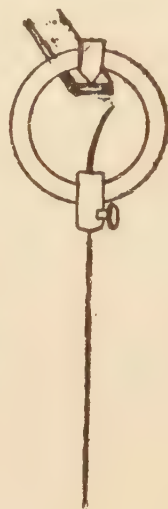
EXPERIMENT 19

BORDA PENDULUM

Aim:—To determine the value of “ g ”, the acceleration due to gravity at the place, using the Borda pendulum.

Apparatus required:—The Borda pendulum, stop-watch.

Description:—The Borda pendulum consists of a heavy spherical bob of lead or iron, about 10 cms. in diameter, suspended by a long steel wire, several metres in length. The upper end of the wire is passed through a screw chuck attached to the bottom of a circular ring of brass, which also carries a knife-edge. The knife-edge rests on a thick glass plate. The glass plate is mounted on the top of a rigid support fixed very near the ceiling. The lower end of the wire passes through another chuck which can be screwed into a hole in the spherical bob.



Procedure:—Pass the upper end of the wire through the chuck in the brass ring and screw it tightly. Place the brass ring on the support, with the knife-edge resting on the glass plate. Pass the lower end of the wire through the chuck in the bob and screw the chuck into the hole in the bob. Tighten the chuck so that the wire is gripped firmly. The length of the wire is such that the bob hangs just a foot above the floor. Compare the stop-watch with a standard clock, if available, and find out if any correction is needed for its readings.



Fig. 36

Note the position of rest of the pendulum, by drawing a vertical line on the wall behind it. A mounted card board can also be used for the purpose.

Stand in front of the pendulum and set it in vibration. The amplitude may be about 10 cms. The first few oscillations are ignored. When the pendulum is oscillating regularly, without wobbling, start the stop-watch when the pendulum wire passes across the reference line behind. When the wire passes again

across the line in the same direction, it completes one oscillation. Note the time taken for 100 to 150 oscillations. Repeat the experiment three or four times.

Place the top surface of a large wooden cube flush with the bottom of the bob and measure carefully the distance from the surface on which the knife-edge rests to the top surface of the cube. Let this be L .

Using a vernier calipers, measure the diameter of the bob accurately. Take about six readings for the diameter and find the average. Calculate the radius r .

Calculations :—The length l of the pendulum from the point of suspension to the centre of the bob ($L - r$). Let the average period of oscillation for the length be T . The pendulum is really a compound pendulum and the length of the equivalent simple pendulum is

$$l + \frac{\frac{2}{5} r^2}{l} \text{ or } l \left\{ 1 + \frac{2 r^2}{5 l^2} \right\}$$

$$\therefore T = 2 \pi \sqrt{\frac{l \left\{ 1 + \frac{2 r^2}{5 l^2} \right\}}{g}}$$

$$\therefore g = \frac{4 \pi^2 l \left\{ 1 + \frac{2 r^2}{5 l^2} \right\}}{T^2}$$

Calculate g .

Tabulate the results as follows :—

$$L = \text{cms} ; r = \text{cms.} \therefore l = (L - r) \text{ cms.}$$

Number of Trial	Length of the pendulum l	Time for 150 oscillations	Period of oscillation T
-----------------	-------------------------------	---------------------------	------------------------------

$$\therefore g = \frac{4 \pi^2 l \left\{ 1 + \frac{2 r^2}{5 l^2} \right\}}{T^2} .$$

$\therefore$ The acceleration due to gravity at the place = cms/sec².

EXPERIMENT 20

COMPOUND PENDULUM

Aim :—To determine the value of “ g ”, the acceleration due to gravity at the place, using a compound pendulum and to calculate “ k ” the radius of gyration of the pendulum about its centre.

Apparatus required :—Compound pendulum, a knife-edge rigidly mounted, stop-watch.

Description :—The compound pendulum is a uniform brass or iron bar of rectangular cross-section, about a metre long, 2 cms. broad and about 0.5 cm. thick. A number of neat circular holes (18 to 20 in number) about 6 mm. in diameter are bored all over it from one end to the other. The bar can be suspended from a knife-edge about any of these holes. The knife-edge is made of hard steel and has a sharp edge. It is fixed to a rigid support so that it is horizontal.

Procedure :—The stop-watch is first compared with a standard clock to find out, if its readings require any correction. The bar is supported on the knife-edge from the top-most hole. To enable the bar to oscillate without wobbling, a brass tube about 2 cms. in length and which fits into the holes of the bar is inserted into the hole and the bar then suspended from the knife edge. The bar is set in vibration. Leaving out the first two or three oscillations, the time taken for about 50 to 100 oscillations is noted. Two readings are taken. Suspend the bar from each of the holes in turn and note the times. When the centre of the bar is approached, the period increases considerably and only a few

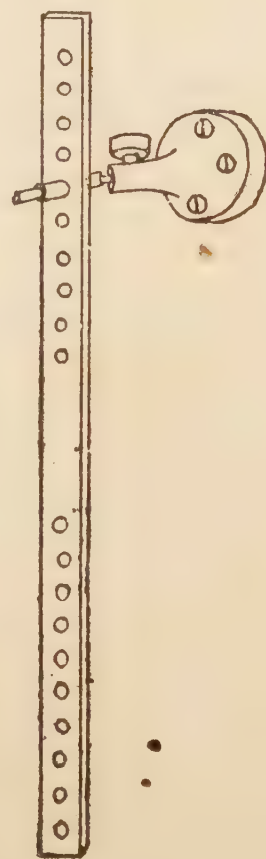


Fig. 37

oscillations will be made. Turn the bar round and continue till the last hole at the other end is reached. Measure the distance from one end of the bar to the point of support in each case, allowing for the thickness of tube used.

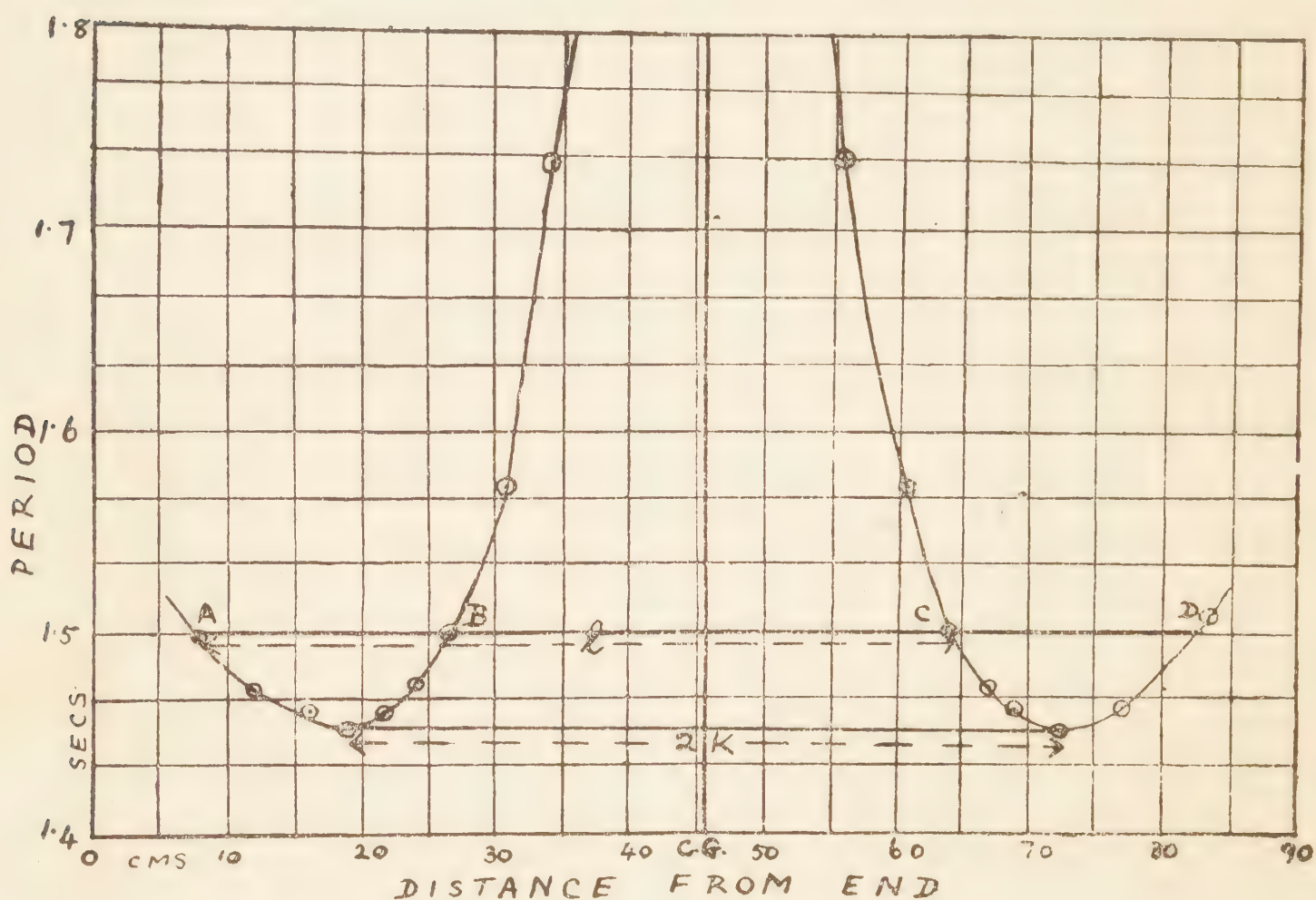


Fig. 38

Calculate the period of oscillation in each case. Plot a graph, representing the lengths measured from one end of the bar along the X axis and the corresponding periods of oscillation along the Y axis. The curve obtained will consist of two disconnected branches which will be exactly similar and symmetrical about the central line passing through the centre of gravity. Any horizontal line will cut the curve at four points A, B, C, D. Hence, for any particular period of oscillation, there will be four points of suspension. The length between any two alternate points, AC or BD, will be the length of the equivalent simple pendulum, having the same period.

Tabulate the readings as follows :—

No. of hole	Distance from one end cms.	Time for 100 oscillations			Period of oscillation secs.
		(1) secs.	(2) secs.	Mean secs.	
2	7.9	150.2	150.0	150.1	1.501
3	11.9	147.2	147.4	147.3	1.473
4	15.8	146.0	146.0	146.0	1.460
5	18.7	145.0	145.0	145.0	1.450
6	21.7	146.0	146.0	146.0	1.460
7	23.8	147.2	147.2	147.2	1.472
8	26.8	150.0	150.0	150.0	1.500
9	30.8	157.0	157.0	157.0	1.570
10	34.7	173.4	173.4	173.4	1.734
11	56.5	173.2	173.4	173.3	1.733
12	60.4	157.0	157.2	157.1	1.571
13	64.4	150.0	150.0	150.0	1.500
14	67.4	147.0	147.0	147.0	1.470
15	69.5	146.2	145.8	146.0	1.460
16	72.5	145.2	145.0	145.1	1.451
17	75.5	146.0	146.2	146.1	1.461
18	83.4	150.6	150.8	150.7	1.507

Draw the graph. Draw lines parallel to the X axis corresponding to definite periods of oscillations. From these lines, find the lengths of the equivalent simple pendulums having the particular period t . If l is the length of the equivalent simple pendulum and T is its period,

$$T = 2\pi \sqrt{\frac{l}{g}} \text{ or } g = \frac{4\pi^2 l}{T^2}$$

Calculate “ g ”.

Tabulate the results :—

Length of equivalent simple pendulum “ l ” from graph in cms.	Period of oscillation “ T ” from graph secs.	$g = \frac{4\pi^2 l}{T^2}$ cms./sec. ²
54.0	1.47	987.4
54.4	1.48	980.5
55.2	1.49	981.6
56.0	1.50	982.6
Mean		983.0 cms. per sec. ²

$\therefore$ The mean value of “ g ” the acceleration due to gravity at the place. $\} = 983.0 \text{ cms./sec.}^2$

Radius of gyration :

Draw the line about which the two branches are symmetrical. Draw the line parallel to the X axis which touches the two curves at their bottom. The distance on this line between the bottom most points of the two branches of the curve is equal to $2k$ where k is the radius of gyration of the bar about its centre of gravity.

In the graph drawn,

$$2k = 53.0 \text{ cms. } \therefore k = 26.5 \text{ cms.}$$

The period of oscillation corresponding to this is 1.45 seconds. The length $2k$ represents the length of the equivalent simple pendulum of the same period.

$$\therefore "g" = \frac{4\pi^2 \times 53}{1.450^2} = 992.2 \text{ cms./sec.}^2$$

[The value of "g" is too high. With a compound bar pendulum, a high degree of accuracy is not possible].

EXPERIMENT 21

KATER'S PENDULUM

Aim :—To determine the value of "g", the acceleration due to gravity at a place, with the Kater's pendulum.

Apparatus required :—Kater's pendulum, Stop-watch, Reading Telescope, Standard Seconds Clock.

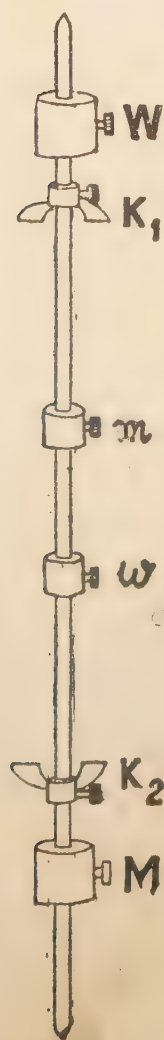


Fig. 39

Description of Apparatus :—A common form of the Kater's pendulum consists of a cylindrical rod of steel or brass, about 120 cms. in length and 1 cm. in diameter. It tapers to a point at either end. Sliding over the rod are two cylinders of the same size, one of brass M and the other of wood W about 8 cms. in length and 3 cms. in diameter, and two smaller cylinders of equal size, one of brass m and the other of wood w . They are fitted with side screws by which they could be clamped on the rod at any position. There are also two exactly similar knife-edges K_1, K_2 which slide over the rod and can be clamped on the rod at any position by means of side screws. They are mounted facing each other. The Kater's pendulum can be suspended so as to swing to and fro freely, by either knife-edge resting on a glass or steel plate attached to a rigid support. The larger cylinders as well as the two smaller ones are

clamped on the rod on either side of the centre symmetrically. The wooden cylinders are provided to compensate for air resistance.

Procedure :—If the two knife-edges occupy such positions, on either side of the centre of gravity and at unequal distances from it, that the periods of oscillation about them are exactly equal, then the distance between them is equal to the length of the equivalent simple pendulum. If the period and the length are known, “ g ”, the acceleration due to gravity, can be calculated. It is very tedious to adjust the periods to be exactly equal. So, two positions of the knife-edges are found for which, the periods of oscillation are almost equal, and by applying a small correction, “ g ” is calculated.

First adjust the positions of the larger cylinders so that they are near either end of the rod and equidistant from the centre. Adjust the smaller cylinders so that they are near the centre on either side of it and equidistant from it. Move the knife-edges so that they are on either side of the centre of gravity of the rod and at unequal distances from it.

The period of oscillation of the pendulum can be determined using a stop-watch. Allow the pendulum to oscillate about one of the knife-edges and note the time for 50 oscillations. Calculate the period. Suspend it about the other knife-edge and find the period as before. If the difference in period is appreciable, alter the positions of the knife-edges or of the two smaller cylinders. Again find the period. Proceed thus, till the periods of oscillation about the two knife-edges are almost equal.

Now, find the periods accurately by noting the time for 100 oscillations, two or three times and taking the average. The average time taken divided by 100 gives the period fairly accurately.

Method of coincidences :—A more accurate method of measuring the period of oscillation, is possible, if a standard seconds clock is available. The Kater's pendulum is mounted in front of the pendulum of the clock. A telescope is set up at a distance from the two, on a level with their lower ends and focussed

them. The vertical cross-wire is adjusted to coincide with their equilibrium position. The Kater's pendulum is set in vibration. Looking through the telescope, note when the two pass the equilibrium position together. If they are watched further, they will be seen to fall out of step, after this coincidence, either one or the other gaining unless their periods are exactly equal. After some time they will again coincide and pass the equilibrium position together. The interval between two coincidences will be large, if the difference between the periods is small and *vice versa*. Observe the tapering end of the Kater's pendulum to note the coincidences accurately.

Between two coincidences in the same direction, one of them gains one complete oscillation over the other. Let the interval between two coincidences be T and the period of the clock 2 seconds. Then, the number of oscillations n made by the clock is given by

$$2n = T \text{ or } n = \frac{T}{2}$$

If the pendulum gains over the clock, during this interval, between two coincidences it makes one more oscillation than the other. If its period is t , then

$$(n + 1)t = T \text{ or } t = \frac{T}{n + 1} = \frac{2T}{T + 2}$$

From this t can be calculated. If the Kater's pendulum lags behind the clock, then,

$$(n - 1)t = T \text{ or } t = \frac{2T}{T - 2}$$

Thus, knowing T , the time interval between two coincidences, the period of the Kater's pendulum can be calculated.

I. Method of interpolation for calculating "g"

Find the periods of oscillation t_1 and t_2 , about each of the knife-edges by one of the methods mentioned above. Measure the distance (l_1) between the knife-edges accurately, using a beam compass. Move the knife-edge near the lighter cylinder by 3 or 4 cms. Again, find the periods of oscillation t_3 and t_4 about each of the knife-edges as before. Measure carefully with a beam compass the distance (l_2) between the knife-edges. t_1 and t_3 are

the periods about knife-edge I and t_2 and t_4 , the periods about knife-edge II. Plot a graph representing the distances between

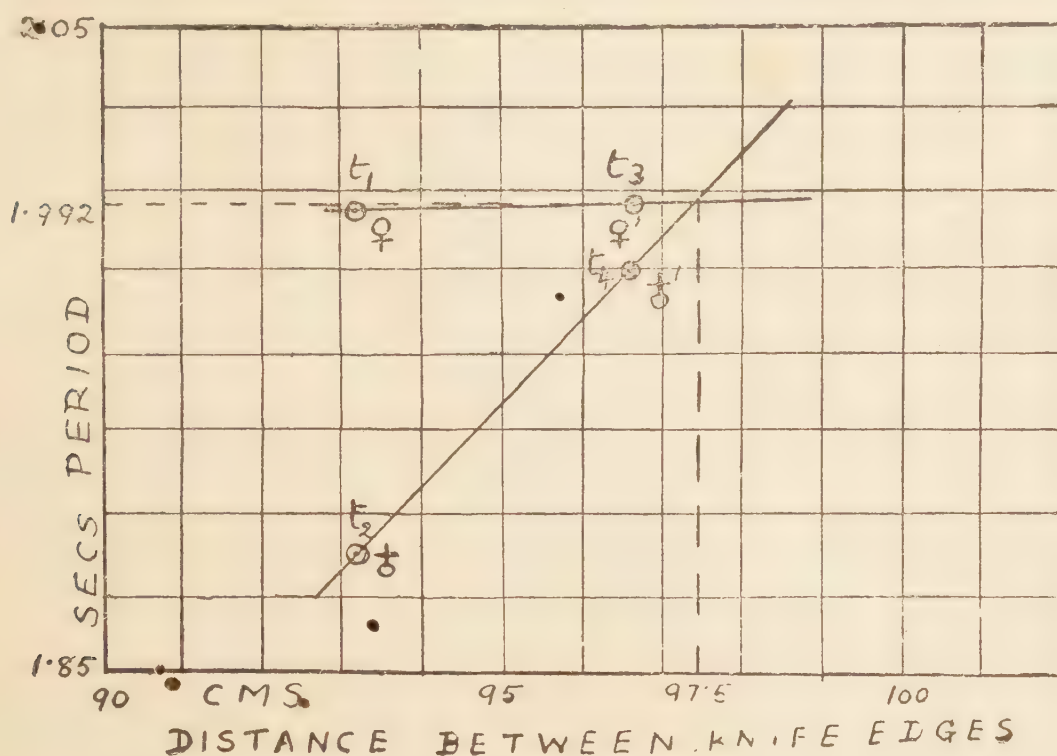


Fig. 40

the knife-edges along the X axis and the periods of oscillation along the Y axis. Join the points (t_1, l_1) , (t_3, l_2) by a straight line. Similarly join the points (t_2, l_1) , (t_4, l_2) by a straight line. Note the period t and the distance l corresponding to the point of intersection of the two lines. The distance l represents the length of the equivalent simple pendulum of period t . Calculate "g", using the formula $g = \frac{4\pi^2 l}{t^2}$.

Tabulate the readings as follows :—

(1) Distance between knife-edges = 93.3 cms.

Knife- edge I					Knife edge II				
No. of Coin- cidence	Time of Transit	No. of Coin- cidence	Time of Transit	Dif. in Time	No. of Coin- cidence	Time of Transit	No. of Coin- cidence	Time of Transit	Dif. in Time
1	51'23"	4	73'50"	22'27"	1	41'4"	4	42'43"	1'39"
2	58'55"	5	81'17"	22'22"	2	41'35"	5	43'15"	1'40"
3	66'14"	6	88'38"	22'24"	3	42'10"	6	43'47"	1'37"
[Kater gains]			Mean	22'24"	[Kater gains]			Mean	1'39"

The intervals between two consecutive coincidences are $7' 28''$ and $33''$ respectively

$$\therefore t_1 = \frac{2 \times 448}{450} = 1.991 \text{ seconds.}$$

$$\text{and } t_2 = \frac{2 \times 33''}{35} = 1.882 \text{ seconds.}$$

(2) Distance between knife-edges = 96.7 cms.

Knife edge II					Knife-edge I				
No. of coin- cidence	Time of transit	No. of coin- cidence	Time of transit	Dif. in time	No. of Coin- cidence	Time of transit	No. of Coin- cidence	Time of transit	Dif. in time
1	23' 30''	4	30' 47''	7' 17''	1	42' 45''	4	66' 8''	23' 23''
2	25' 57''	5	33' 12''	7' 15''	2	50' 33''	5	73' 57''	23' 24''
3	28' 24''	6	35' 37''	7' 13''	3	58' 20''	6	81' 40''	23' 20''
[Kater gains]			Mean	7' 15''	[Kater gains]			Mean	23' 22''

The intervals between two consecutive coincidences are $2' 25''$ and $7' 47''$ respectively.

$$\therefore t_4 = \frac{2 \times 145}{147} = 1.973 \text{ seconds.}$$

$$\text{and } t_3 = \frac{2 \times 467}{469} = 1.992 \text{ seconds.}$$

From the graph, the length l of the equivalent simple pendulum is found to be 97.5 cms. and the period is found to be 1.992 seconds.

$$\therefore g = \frac{4\pi^2 l}{t^2} = \frac{4 \times 3.1416^2 \times 97.5}{1.992^2} = 970 \text{ cms./sec.}^2$$

II. Bessel's method for calculating "g"

Another method of calculating "g" is by applying Bessel's correction. Let t_1 and t_2 be the periods of oscillation about the two knife-edges. They must be almost equal. Let l_1 and l_2 be the distances of the respective knife-edges from the centre of gravity. Then

$$t_1 = 2\pi \sqrt{\frac{k^2 + l_1^2}{l_1 g}} \text{ and } t_2 = 2\pi \sqrt{\frac{k^2 + l_2^2}{l_2 g}}$$

where k is the radius of gyration of the pendulum about a horizontal axis through the centre of gravity. Squaring and cross-multiplying, we get

$$l_1 g t_1^2 = 4\pi^2 (k^2 + l_1^2)$$

$$l_2 g t_2^2 = 4\pi^2 (k^2 + l_2^2)$$

$$\therefore g (l_1 t_1^2 - l_2 t_2^2) = 4\pi^2 (l_1^2 - l_2^2)$$

$$\therefore \frac{4\pi^2}{g} = \frac{l_1 t_1^2 - l_2 t_2^2}{l_1^2 - l_2^2} = \frac{t_1^2 + t_2^2}{2(l_1 + l_2)} + \frac{t_1^2 - t_2^2}{2(l_1 - l_2)}$$

From this "g" can be calculated

Hence, having found t_1 and t_2 , measure l_1 and l_2 by balancing the Kater's pendulum on a knife-edge support and finding the centre of gravity.

Tabulate the readings as follows :—

Distance between the knife-edges = 96.6 cms.

Knife-edge I					Knife-edge II				
No. of coincidence	Time of transit	No. of coincidence	Time of transit	Dif. in time	No. of coincidence	Time of transit	No. of coincidence	Time of transit	Dif. in time
1	47' 10"	5	65' 48"	18' 38"	1	20' 0"	5	50' 10"	30' 10"
2	51' 47"	6	70' 25"	18' 38"	2	27' 30"	6	57' 40"	30' 10"
3	56' 30"	7	75' 9"	18' 39"	3	35' 5"	7	65' 20"	30' 15"
4	61' 12"	8	79' 49"	18' 37"	4	42' 40"	8	72' 55"	30' 15"
[Kater gains]			Mean	18' 38"	[Kater gains]			Mean	30' 12½"

The average interval of time between two coincidences when supported on knife-edge I } = 4' 40"

$$\therefore t_1 = \frac{2 \times 280}{282} = 1.986 \text{ seconds}$$

The average interval of time between two coincidences when supported on knife-edge II } = 7' 33"

$$\therefore t_2 = \frac{2 \times 453}{455} = 1.991 \text{ seconds}$$

$$l_1 = 73.9 \text{ cms.}; l_2 = 22.7 \text{ cms.}$$

$$\therefore \frac{4 \pi^2}{g} = \frac{1.986^2 + 1.991^2}{2(73.9 + 22.7)} + \frac{1.986^2 - 1.991^2}{2(73.9 - 22.7)}$$

$$= 0.0409 - 0.00019 = 0.0407$$

$$\therefore g = \frac{4 \pi^2}{0.0407} = 973 \text{ cms./sec.}^2$$

So, the acceleration due to gravity at the place is 973 cms./sec.²

EXPERIMENT 22

BIFILAR PENDULUM

Aim :—To determine the Moment of Inertia of a body, using the Bifilar Pendulum.

Apparatus required :—Metallic disc or wooden block of rectangular cross-section.

Description of Apparatus :—The metallic disc or wooden block used is a rectangular parallelopiped of sides, say, a, b and c.

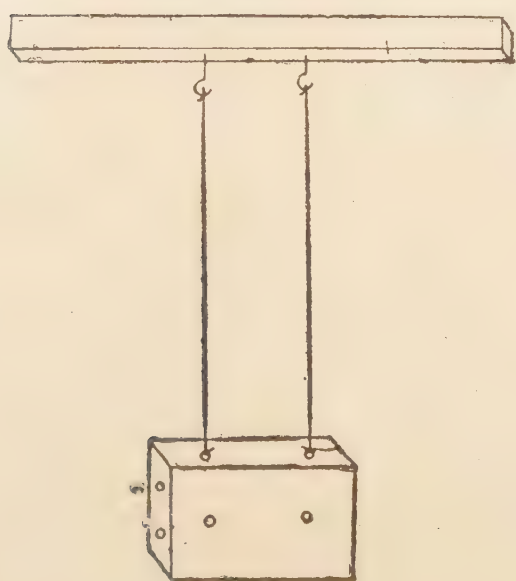


Fig. 41

Three of the faces bounded by sides ab, bc and ca are provided with two screws or hooks at their centre, symmetrically situated. The disc could be suspended from a rigid support by two strings fixed to these screws or hooks. The disc thus suspended forms a Bifilar Pendulum.

Procedure :—Suspend the disc by two long strings of equal length attached to the screws or hooks fixed in one of the faces from a rigid horizontal support. The screws or hooks are symmetrically situated on the face. So the disc will take up a position of equilibrium with the strings in a vertical plane. The centre of gravity of the face will be midway between the strings. The strings may be adjusted to be parallel. But this is not essential. Gently twist the disc about a vertical axis passing through the centre of gravity and let go. The disc will execute oscillations.

Note the time for 15 to 20 oscillations and calculate the period of one oscillation. Repeat half a dozen times. Then suspend the disc by another face in a similar manner. See that the strings are of equal length and in the same vertical plane. As before, find the mean period of angular oscillation about the vertical axis passing through the centre of gravity of the disc. Repeat the experiment, suspending the disc by the third face. Measure the length of the strings supporting the disc. Alter the length of the strings and repeat the experiment three or four times. Remove the disc and find its weight.

Calculations :—The period of oscillation of a bifilar pendulum about a vertical axis passing through the centre of gravity situated between the strings, is given by,

$$T = 2 \pi \sqrt{\frac{I l}{Mg d_1 d_2}}$$

where T is the period of oscillation,

I is the moment of Inertia about a vertical axis passing through the centre of gravity,

l is the length of the suspension strings

M is the mass of the disc

$2 d_1$ is the distance between the points of suspension on the support

$2 d_2$ is the distance between the points on the face of the disc to which the strings are attached.

If $2 d_1 = 2 d_2 = 2d$, then,

$$T = 2 \pi \sqrt{\frac{I l}{Mg d^2}}$$

Moment of Inertia of the disc.

$$T_1^2 = \frac{4 \pi^2 l I_1}{Mg d^2}$$

$$\therefore I_1 = \frac{T_1^2 Mg d^2}{4 \pi^2 l}$$

So, if T_1 , M , d and l are found out, I_1 the moment of Inertia of the disc about an axis perpendicular to the face ab and passing through its centre of gravity, can be calculated.

Similarly, I_2 and I_3 can be calculated from the formulae,

$$I_2 = \frac{T_2^2 Mgd^2}{4\pi^2 l}$$

$$\text{and } I_3 = \frac{T_3^2 Mgd^2}{4\pi^2 l}$$

Tabulate the results as follows :—

Length of the string = cms.
 Distance $2d$ between points of suspension = cms.
 Mass M of the disc = grms.

Period of oscillation

Trial No.	Face ab horizontal		Face bc horizontal		Face ca horizontal	
	Time for 15 oscillations	Period of oscillation T_1	Time for 15 oscillations	Period of oscillation T_2	Time for 15 oscillations	Period of oscillation T_3
1						
2						
3						
	Mean		Mean		Mean	

Calculate I_1 , I_2 and I_3 from the data.

Verify by calculating I_1 , I_2 and I_3 from the dimensions of the block. [For a rectangular block of length l and breadth b , the moment of inertia about an axis perpendicular to that face is

$$M \left\{ \frac{l^2 + b^2}{12} \right\}.$$

EXPERIMENT 23

YOUNG'S MODULUS BY STRETCHING

(A) Searle's apparatus with micrometer screw and spirit level

Aim :—To determine the Young's Modulus of the material of a wire by stretching, using Searle's apparatus.

Apparatus required :—Searle's apparatus, metre scale, Screw Gauge, slotted weights.

Description :—The apparatus consists of two similar wires of the same material and of equal length, about 4 metres each, fastened firmly to the same rigid support fixed to the ceiling. One of them is the experimental wire while the other is a reference wire. The object of having two wires is to avoid errors due to the changes of length produced by changes of temperature or the yielding of the support. At the lower end of each wire, a rectangular frame is attached. The two frames are connected together by cross links which do not prevent their free, relative motion in a vertical direction but which prevent them from flying apart horizontally. A sensitive spirit level *L* is mounted across the frames, one end of which is pivoted to a rigid cross rod in the frame attached to the reference wire. The other end rests on the tip of a micrometer screw *M*, fixed in the other frame, the axis of the screw being vertical and coinciding with the axis of the experimental wire supporting the frame. A fixed stretching weight is hung from the frame attached to the reference wire. A scale pan or a weight hanger with an initial dead load is hung from the other frame. The weights should be such that both the wires remain stretched. Initially, the bubble in the spirit level is brought to the centre by working the micrometer screw. In this position, the spirit-level is horizontal.

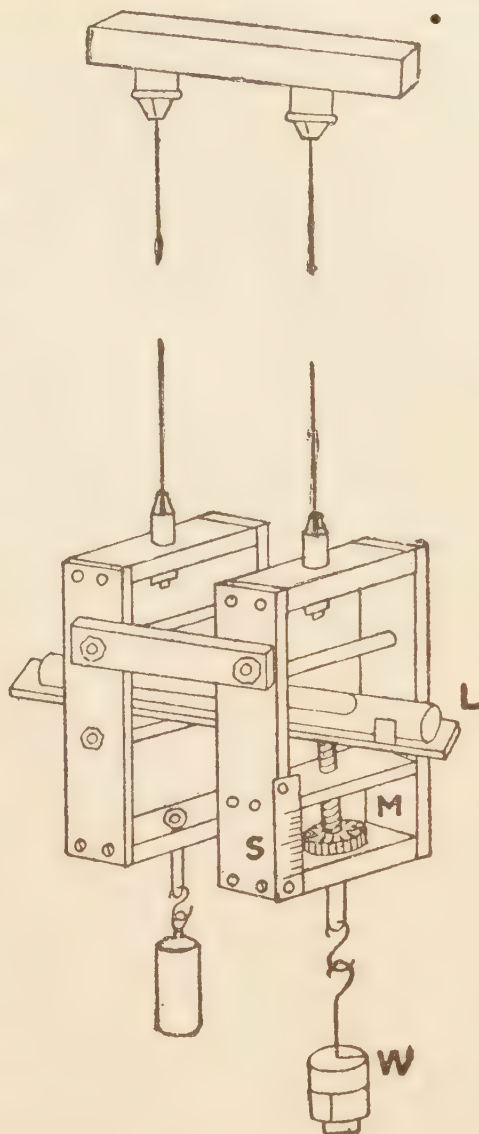


Fig. 42

Procedure :—The graduated head of the micrometer screw moves parallel to a vertical pitch scale *S*. To begin with, find the value of each of the pitch scale divisions. Then, determine the pitch and the least count of the micrometer screw. Take the reading when the bubble is at the centre. It is equal to the pitch scale reading + the coinciding head scale reading, multiplied by the least count. Add equal weights to the hanger, one by one. When a weight is added, the wire is stretched. The frame attached to it moves down and the horizontal position of the spirit level is disturbed. Work up the micrometer screw till the bubble again

comes to the centre. It is obvious that the distance through which the micrometer screw is moved is equal to the extension of the wire. Perform a preliminary set of experiments, by adding equal weights, one by one, and removing them. This is to train the wire to elongate and contract. After a few trials, remove all the weights added, other than the dead weight. Bring back the bubble to the centre and take once again the initial reading of the micrometer screw. Add equal weights, one by one at a time, till the maximum safe load (which depends on the material of the wire and its cross section) is reached. Take the reading at each step, by working the micrometer screw and bringing the bubble to the centre. About 8 to 10 readings must be taken. Remove the weights, one by one, and take the corresponding readings of the micrometer screw.

Then, measure the diameter of the wire, using a screw gauge. Determine the pitch, least count and zero reading of the screw gauge. As the wire is long, measure the diameters at about a dozen different places over its length. At each place, note the diameters in two mutually perpendicular directions. The average of all the readings is the mean diameter of the wire.

Using a long, straight wooden rod, measure the length of the wire from the point where it is gripped at the top, to the point where it is gripped in the frame at the bottom.

Tabulate the readings as follows :—

I. Elongations :—Dead load = 5 kilograms ; Pitch of the scale = 0.5 mm. ; Least count = 0.01 mm.

Stretching Load k. gms.	Reading of micrometer screw			Elongation for 5 kilo- grams mm.
	Load increasing mm.	Load decreasing mm.	Average. mm.	
6	3.460	3.470	3.465	
7	3.600	3.610	3.605	
8	3.735	3.750	3.743	
9	3.875	3.880	3.878	
10	4.010	4.020	4.015	
11	4.165	4.170	4.168	0.703
12	4.300	4.310	4.305	0.700
13	4.445	4.460	4.453	0.710
14	4.580	4.590	4.585	0.707
15	4.715	4.715	4.715	0.700
			Average	0.704 mms

$\therefore$ Average elongation for 5 kilo-grams = 0.704 mm. = 0.0704 cm.

II. Diameter of the wire :

Pitch of the screw gauge = 1 mm.

Least count of the screw gauge = 0.01 mm.

Zero reading = + 0.185 mm.

 $\therefore$ Zero correction = - 0.185 mm.

No. of Trial	Diameter			Corrected reading. mm.
	In one direction mm.	in a $\perp$ r direction mm.	Mean. mm.	
1	1.380	1.380	1.380	1.195
2	1.370	1.360	1.365	1.180
3	1.360	1.360	1.360	1.175
4	1.360	1.360	1.360	1.175
5	1.355	1.355	1.355	1.170
6	1.355	1.355	1.355	1.170
7	1.360	1.355	1.358	1.173
8	1.355	1.355	1.355	1.170
9	1.360	1.355	1.358	1.173
10	1.360	1.360	1.360	1.175
11	1.355	1.360	1.358	1.173
12	1.350	1.360	1.355	1.170
Average				1.175 mm.

 $\therefore$ The average diameter of the wire = 1.175 mms.

= 0.1175 cms.

III. Length of the wire = 302.5 cms.

$$\begin{aligned} \text{Now, Young's Modulus } q &= \frac{\text{Stress}}{\text{Strain}} \\ &= \frac{\text{Stretching force per unit area}}{\text{Elongation per unit length}} \\ &= \frac{Mg / \pi r^2}{l / L} = \frac{Mg L}{\pi r^2 l} \end{aligned}$$

$$\therefore q = \frac{5000 \times 978 \times 302.5}{3.1416 \times (0.0588)^2 \times 0.0704} = 19.38 \times 10^{11} \text{ dynes per sq. cm.}$$

$\therefore$ The Young's Modulus of the material of the wire is 19.38×10^{11} dynes per sq. cm.

Steel wire was used in the above experiment. Usually, copper wire is used, since greater elongations will be obtained for the same load, other conditions being equal.

Graph :—Draw a graph, representing load along the X axis and the corresponding readings of the micrometer screw along the Y axis. It will be a straight line graph. It can be used for finding the value of an unknown load.

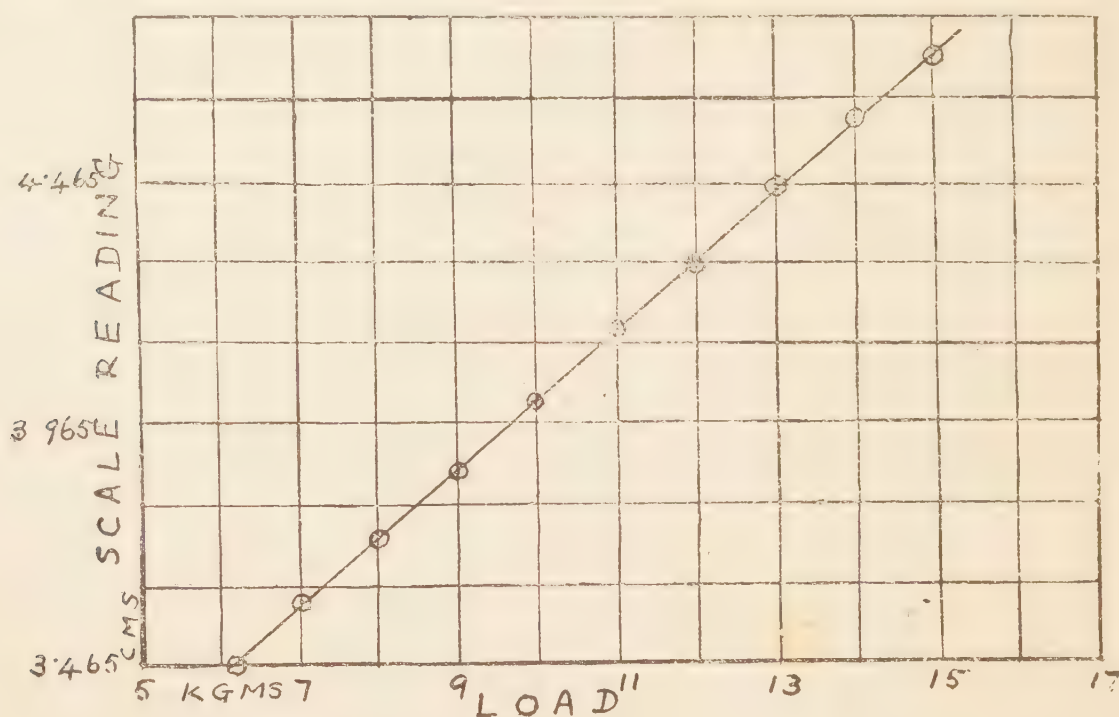


Fig. 43

(B) Searle's apparatus using Optic Lever, Telescope and Scale

Description of Apparatus :—The Searle's apparatus used is a modified form of the apparatus used in the previous experiment.

The spirit level, the micrometer screw and the vertical scale are removed. Each of the rectangular frames is provided with a cross-bar which is flat, both of them being at the same level. An optic lever is placed across the two frames with its hind legs on the cross-bar in the frame attached to the reference wire. The front leg rests on the cross-bar in the frame attached to the experimental wire.

Procedure :—Set up a telescope and scale in front of the optic lever, at a distance of about a metre from it. Turn the telescope so that its axis is horizontal and passes through the centre of the mirror in the optic lever. Keep the scale vertical. Add a dead load to the weight hanger suspended from the frame to which the experimental wire is attached. Adjust the eye-piece so that the cross-wires are distinctly seen. Focus the telescope on the image of the scale seen in the mirror. Tilt it slightly so that the

horizontal cross-wire coincides with a definite division on the scale.

A preliminary loading and unloading of weights on the weight hanger is gone through to train the wire to elongate and contract.

Start again from the beginning with the dead load alone. Note the reading on the scale coinciding with the horizontal cross-wire. Gently place a weight on the hanger. The wire elongates and the frame attached to it moves down. So, the front leg of the optic lever moves down. Hence, the mirror tilts and the scale reading changes. Note the scale reading. Add equal weights, one by one, till the maximum safe load is reached. Take the scale reading at each step. Remove the weights, one by one, and take the corresponding readings. Take about 8 to 10 readings.

Find the length of the wire as accurately as possible. Measure the diameter of the wire at a dozen places on it, at each place in two directions perpendicular to each other, with a screw gauge and find the mean diameter. Measure the distance D of the mirror from the scale. Measure the distance d between the front leg of the optic lever and the plane containing the rear legs.

Tabulate the readings as follows :—

Distance of scale from mirror = D cms.

Stretching Force M	Reading on Scale			Distance between front and rear legs of optic lever (d)	Distance of scale from mirror (D)	Elongation l for $M_2 - M_1$ grams wt. $\frac{(S_2 - S_1) d}{2 D}$
	While loading	While unloading	Mean S			

If S_1 is the scale reading corresponding to M_1 grams wt., and S_2 corresponding to M_2 grams wt., the elongation l for $(M_2 - M_1)$ grams weight or Mg dynes is given by

$$l = \frac{(S_2 - S_1) \times d}{2 D}$$

For this purpose, divide the readings into two groups. Suppose ten readings are taken. Then, M_1 and M_2 represent the first and sixth weights, S_1 and S_2 represent the corresponding readings on the scale and so on. Find the mean elongation l from the table.

Calculate as follows :

$$q = \frac{Mg L}{\pi r^2 l} = \frac{Mg L}{\pi r^2} \times \frac{2 D}{(S_2 - S_1) d}$$

where L is the length of the wire, Mg the load, and r the mean radius of the wire.

EXPERIMENT 24

YOUNG'S MODULUS BY BENDING—(CANTILEVER)

Aim:—To determine the Young's Modulus of Elasticity of a cantilever by bending, using a pin and microscope to measure the depressions of its loaded end.

Apparatus required:—A long, uniform rectangular beam, Vernier Microscope, slotted weights, table clamps.

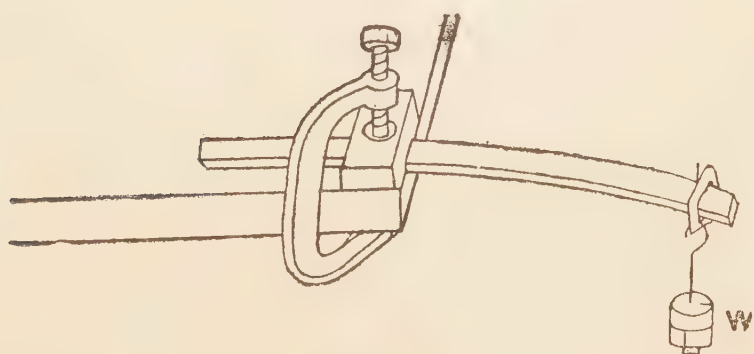


Fig. 44

Procedure:—The long, uniform beam is placed on a table near one of its corners, parallel to and coinciding with the edge of the table. Adjust it so that about three-fifths of its length is

projecting beyond the table. Clamp the portion over the table tightly at two places using table clamps. One of the clamps must be close to the edge of the table and the other a little away from it. The projecting part of the beam serves as a

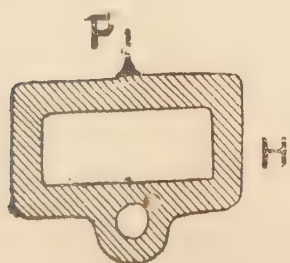


Fig. 45

cantilever. Slide over the beam a weight carrier. (See Fig.). It also carries a pin index P at its top. Adjust it so that it is near the free end of the beam. Set up the vernier microscope near the free end so that it is at the same height. Turn the microscope till its axis

is horizontal and passes through the pin index. Adjust the eye-piece so that the cross-wires are clearly seen. Focus the microscope on the pin. Raise it or lower it till the tip of the pin is in the field of view coinciding with the point of intersection of the cross-wires.

Find the least count of the vernier in the vertical scale of the microscope and note the initial reading when the tip of the pin coincides with the point of intersection of the cross-wires. Suspend a weight hanger. Perform a preliminary experiment by adding and removing equal weights, one by one. This is to train the beam to bend and unbend. Allow the beam to come to rest. Adjust again the microscope so that the point of intersection of the cross-wires coincides with the tip of the pin. Note the reading on the vertical scale. Add equal weights, one by one, and take the corresponding readings by adjusting the position of the microscope so that the point of intersection of the cross-wires coincides with the tip of the pin. After the safe maximum load has been added and the reading taken, remove the weights, one by one, and take the readings. Take about 8 to 10 readings. Alter the length of the cantilever and repeat the experiment. Take readings for three or four different lengths of the cantilever. Measure carefully the length in each case, from the point where the load is applied to the point where it is clamped.

Remove the cantilever and measure accurately its breadth and height using a vernier calipers or screw gauge. Readings must be taken at more than six places on the beam, spaced equally along the beam. Take particular care in the measurement of the height as its third power is involved in the formula.

Calculations :—Assume that the mass of the beam is negligible. If y is the depression produced at the end of the cantilever due to a load Mg , then

$$y = \frac{Mg l^3}{3 A k^2 q}$$

where l is the length of the projecting portion of the cantilever and q , the Young's modulus of the beam. If the beam is rectangular in cross section, $A = b \times d$ and $k^2 = \frac{d^2}{12}$, where b is the breadth and d the height of the beam.

$$\therefore y = \frac{Mgl^3}{3 \times \frac{bd^3}{12} \times q} = \frac{4Mgl^3}{bd^3q}$$

$$\therefore q = \frac{4Mgl^3}{bd^3y}$$

Tabulate the results as follows :—

I. Depressions at the end of the cantilever.

Least count of the Vernier Microscope = 0.001 cms.

Length of Cantilever cms.	Load grams.	Reading			Load grms.	Reading			Difference in Reading cms.
		When loading cms.	When u-nload- ing cms.	Mean cms.		When loading cms.	When un-load- ing cms.	Mean cms.	
64	200	6.229	6.206	6.218	500	4.167	4.152	4.160	2.058
	300	5.543	5.518	5.531	600	3.495	3.480	3.488	2.043
	400	4.854	4.837	4.846	700	2.802	2.802	2.802	2.044
57								Mean	2.048
	200	6.487	6.476	6.482	500	5.005	4.954	5.000	1.482
	300	5.993	5.984	5.989	600	4.522	4.512	4.517	1.472
	400	5.502	5.493	5.498	700	4.030	4.030	4.030	1.468
Mean									1.474

II. Screw gauge readings—Height of beam

Least count = 0.001 mm ;

Zero reading = -0.06 mm

Zero correction = +0.06 mm

Mean height of beam (average of six readings) } = 3.23 mm.
= 0.323cms.

III. Vernier calipers readings—Breadth of beam

Least count = 0.01 cm ; No Zero error.

Mean breadth of beam (average of six readings) } = 2.51 cms.

IV.

Length of canti- lever l cms.	Mean depression for 300 grams y cms.	$\frac{l^3}{y}$
64	2.048	12.80×10^5
57	1.474	12.55×10^5
Mean		12.68×10^5

$$\begin{aligned}\therefore q &= \frac{4 \times 300 \times 980 \times l^3}{2.51 \times (0.323)^3 \times y} \\ &= 17.63 \times 10^{11} \text{ dynes/cm}^2.\end{aligned}$$

$\therefore$ The Young's modulus of the material of the beam (iron) is 17.63×10^{11} dynes/sq. cm.

EXPERIMENT 25

YOUNG'S MODULUS BY BENDING—(NON-UNIFORM)

(A) Pin and Microscope Method

Aim :—To determine the Young's Modulus of Elasticity of a beam by non-uniform bending, using a pin and microscope for measuring the depressions when a load is applied at the centre.

Apparatus required :—A long, uniform rectangular beam, two tall knife-edge supports, Vernier Microscope, slotted weights.

Description of Apparatus and Procedure :—The long, uniform beam is placed horizontally, resting on the two knife-edge supports S_1 , S_2 . The beam is adjusted so that equal lengths of it project beyond the supports. (This, however, is not quite important). A thin, rectangular plate of iron or brass, (Fig 45) with a central slot cut in it is slipped over the beam and adjusted to rest on it, midway between the knife-edges. The plate has a pin firmly attached vertically, at the centre of the top edge of the plate. This pin serves as an index to facilitate measurements. The plate has a circular hole near the lower edge. A hook is hung from this hole and a slotted weight hanger is suspended from the hook. A preliminary experiment is done by adding equal weights, one by one, and then removing them likewise to train the beam to bend and unbend,

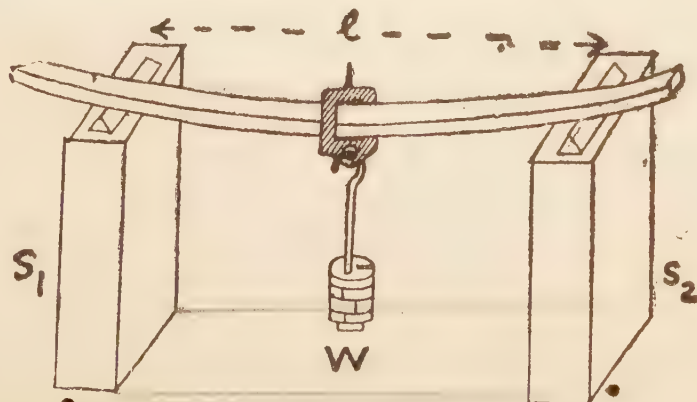


Fig. 46

Place a vernier microscope in front of the beam. Turn the microscope till its axis is horizontal. Adjust its height so that its axis passed through the tip of the index pin.

Determine the least count of the vernier attached to the microscope. Adjust the plate so that it rests on the bar exactly midway between the knife-edges. The microscope is focussed on the tip of the pin fixed to the plate. Adjust its position so that the tip of the pin coincides with the point of intersection of the cross-wires. Take the initial reading on the vertical scale. It is equal to the main scale reading + the coinciding division on the vernier scale multiplied by the least count. Add equal weights to the hanger, one by one, gently. When a central load is applied to the beam, it bends. The maximum depression is produced at the centre. As the outline of the beam does not have the shape of the arc of a circle, the bending is said to be *non-uniform*. After each weight is added, adjust the microscope so that the tip of the pin coincides with the point of intersection of the cross-wires. Take the reading as before. After the maximum safe load has been added and the corresponding reading taken remove the weights, one by one. As each weight is removed adjust the microscope for coincidence between the tip of the pin and the point of intersection of the cross-wires and take the reading. Take about 8 to 10 readings.

Alter the length between the supports. Adjust the index plate again to lie exactly midway between the knife-edges and repeat the experiment. Take readings for about three or four different lengths.

Remove the beam. Measure its breadth and height accurately at half a dozen places on it, spaced equally along the beam using a vernier calipers or screw gauge. As the third power of the height is involved in the formula, it must be measured very accurately.

Tabulate the readings as follows :—

The beam used is a metre scale.

I. *Depressions produced when a central load is applied—Metre scale.*—Least count of the vernier microscope = 0.01 cms.

Length between supports	Load	Reading			Load	Reading			Difference in reading
		When loading	When un-loading	Mean		When loading	When un-loading	Mean	
cms. 50	gms. 0	9.700	9.690	9.695	gms. 200	9.460	9.460	9.460	cms. 0.235
	50	9.650	9.630	9.640	250	9.400	9.400	9.400	0.240
	100	9.580	9.570	9.575	300	9.340	9.340	9.340	0.235
	150	9.530	9.520	9.525	350	9.280	9.280	9.280	0.245
								Mean	0.239
cms 60	gms. 0	9.630	9.620	9.625	gms. 200	9.190	9.200	9.195	cms. 0.430
	50	9.520	9.520	9.520	250	9.080	9.100	9.090	0.430
	100	9.410	9.410	9.410	300	9.990	8.990	9.990	0.420
	150	9.300	9.300	9.300	350	8.890	8.890	8.890	0.410
								Mean	0.423

II. *Breadth of the scale—*

Least count of vernier calipers = 0.01 cm.

The average breadth of the scale measured
with a vernier calipers (mean of six readings) } = 2.56 cms.

III. *Height of the scale—*

Least count of screw gauge = 0.001 cm.

The average height of the scale measured
with a screw gauge (mean of six readings) } = 0.450 cms.

Calculations :—

When a uniform beam of rectangular cross-section is supported horizontally on two knife-edges, and a load applied at the mid-point between the supports, the depression at the centre is given by

$$y = \frac{Mg l^3}{4 b d^3 q}$$

where y = depression at the centre,
 M = load at the centre,
 l = length between the knife-edges,
 b = breadth of beam,
 d = height of beam,
 q = Young's modulus of elasticity,
 and g = acceleration due to gravity at the place.

$$\therefore q = \frac{Mg l^3}{4 b d^3 y}$$

For a given beam, q , b , d , are constant, g is constant. So, for the same load M , $\frac{l^3}{y}$ must be constant.

Length between supports (l) cms.	Average depression at centre for load of 200 gms. (y) cms.	$\frac{l^3}{y}$
50	0.235	5.320×10^5
60	0.423	5.228×10^5
	Mean	5.274×10^5

$$\begin{aligned} \therefore q &= \frac{200 \times 980 \times 5.274 \times 10^5}{4 \times 2.56 \times (0.45)^3} \\ &= 1.11 \times 10^{11} \text{ dynes per sq. cm.} \end{aligned}$$

$\therefore$ The Young's modulus of elasticity of the material of the beam is 1.11×10^{11} dynes/cm.²

Graph :—Other factors being the same, the depression produced y is proportional to the load Mg . So, if a graph is drawn, plotting load along the X axis and depression along the Y axis, the graph obtained will be a straight line. The graph can be used for determining an unknown load. The depression produced by the unknown load is measured and from the graph, the corresponding load is found out.

Cylindrical rod :—If a cylindrical rod is used, the procedure is the same as before. Only the formula to be used is different.

$$q = \frac{Mg l^3}{12 \pi r^4 y}$$

where r is the radius of the rod.

(B) Single Optic Lever method

Aim :—To determine the Young's Modulus of Elasticity of a rectangular beam, using a single optic lever, for measuring the depressions when a load is applied at the centre.

Apparatus required :—A long, uniform rectangular beam, two tall knife-edge supports, single optic lever, telescope and scale, slotted weights, an auxiliary beam similar to the experimental beam.

Procedure :—Place the experimental beam horizontally on the two knife-edge supports, with equal lengths of it projecting beyond the knife-edges. Slip over the beam a loop of thick wire with a hook, to which a weight hanger can be attached. Adjust it so that it is midway between the knife-edges. Place the auxiliary beam on the knife-edges, close to the other beam but without touching it. Their top surfaces must be on the same level. Place the single optic lever on the beams, so that its front leg rests on the experimental beam, exactly midway between the knife-edges and the other two legs, on the other beam. Place the stand carrying the telescope and the scale at a distance of a metre in front of the mirror in the optic lever. Rotate the scale so as to be vertical. Adjust the telescope so that its axis passes through the centre of the mirror. Looking through the telescope, alter the position of the stand till the image of the scale produced by reflection in the mirror is visible in the telescope. Focus the telescope on the scale. Adjust so that the horizontal cross-wire is made to coincide with a definite division on the scale. Add gently equal weights, one by one, to the hanger. Perform a preliminary experiment, adding equal weights, one by one, and removing them likewise. When a weight is added, the beam bends, the single leg is lowered and so the mirror gets tilted. The image of the scale in the telescope moves and the cross-wire coincides with a new division. Take the reading on the scale. When the maximum safe load has been added and the reading taken, remove the weights gently, one by one, and take the corresponding readings on the scale. Take about 8 to 10 readings.

As in the previous experiment, alter the length of the beam between the knife-edges, and keeping the loop carrying the weight

$$\text{Average depression } y \text{ for 400 gms.} = \frac{4.99 \times 8}{70.2 \times 2} = 0.284$$

Average breadth of beam = 2.55 cms. ; Average height of beam = 0.509 cm.

$$\therefore \text{Young's Modulus } q = \frac{Mgl^3}{4bd^3y} = \frac{400 \times 980 \times 50^3}{4 \times 2.55 \times (0.509)^3 \times 0.284} \\ = 1.28 \times 10^{11} \text{ dynes per sq. cm.}$$

$\therefore$ The Young's modulus of elasticity of the material of the beam (metre scale) = 1.28×10^{11} dynes/cm².

Repeat the experiment for one or two more lengths between the knife-edges and tabulate the readings as above.

Graph :—A load-depression graph is drawn, representing load on the X axis and reading of the scale on the Y axis. It will be a straight line. It can be used for determining an unknown load, as explained in the previous experiment.

EXPERIMENT 26

YOUNG'S MODULUS BY BENDING—(UNIFORM)

(A) Pin and Microscope method

Aim :—To determine the Young's Modulus of Elasticity of a beam by uniform bending, using a pin and microscope for measuring the elevations at the centre, when equal loads are applied at the ends, symmetrically.

Apparatus required :—A long, uniform, rectangular beam, two tall knife-edge supports, Vernier Microscope, slotted weights.

Procedure :—Place the beam horizontally, on the two knife-edge supports S_1 , S_2 . Adjust it so that equal lengths of it are projecting beyond the knife-edges.

Fix a pin vertically, exactly at the centre of the beam using some bees' wax. Slip over the beam two loops of thick wire, one at each end of it. The loops have hooks at their bottom from which weight hangers can be suspended.

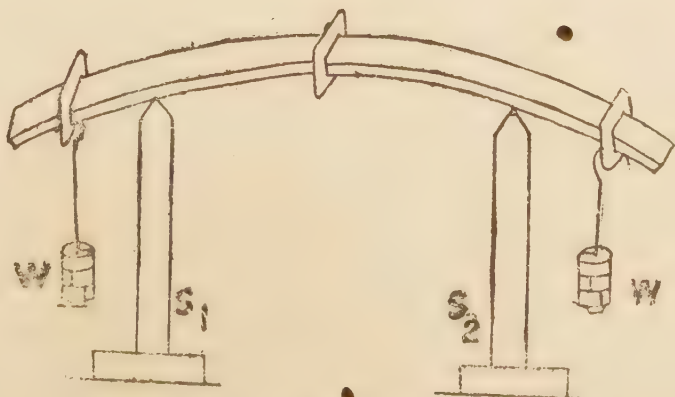


Fig. 47

Keep them equidistant from the ends of the beam and from the knife-edges. Place a vernier microscope in front of the beam. Rotate the microscope so that its axis is horizontal. Adjust its height so that its axis and the top of the pin are in the same horizontal line.

Determine the least count of the vertical vernier scale in the microscope. Focus the microscope on the top of the pin. Adjust its position till the top of the pin coincides with the point of intersection of the cross-wires. Take the initial reading of the vertical scale, by adding to the main scale reading, the coinciding vernier reading. Two equal weights are gently added, one at each end. The beam bends uniformly, assuming the shape of an arc of a circle. The centre is elevated. Perform a preliminary experiment, adding and removing equal weights to the weight hangers, one by one, to train the beam to bend and unbend. Adjust the microscope again so that the top of the pin coincides with the point of intersection of the cross-wires. Take the reading. Add two more equal weights, one at each end, and take the reading. This is repeated till the maximum safe load is reached. Remove the weights one from each end at a time and take the corresponding readings. Take about 8 to 10 readings. Alter the length between the knife-edges and repeat the experiment observing the precautions mentioned. Take sets of readings for about three or four different lengths.

Remove the beam. Measure its breadth and height accurately at half a dozen places on it, spaced equally along the beam, using vernier calipers or a screw gauge. Particular care is taken in measuring the height accurately as its third power occurs in the formula.

Calculations :—Let l be the length of the beam between the knife-edge support, “ a ” distance from the knife-edges to the point where the weights are hung, M the load, b breadth of beam, d height of beam. If y is the elevation at the centre, R the radius of the arc of the circle assumed by the beam,

$$(2R - y)y = \left(\frac{l}{2}\right)^2 \text{ or } 8Ry = l^2, \text{ neglecting } y^2,$$

$$\therefore R = \frac{l^2}{8y}$$

$$\therefore \text{The bending moment} = \frac{q Ak^2}{R} = \frac{8 q Ak^2 y}{l^2}$$

$$\therefore \frac{8q Ak^2 y}{l^2} = Mg \times a.$$

$$\therefore q = \frac{Mg al^2}{8 y Ak^2} = \frac{Mg al^2}{8 y \frac{b d^3}{12}} = \frac{3 Mg al^2}{2 b d^3 y}.$$

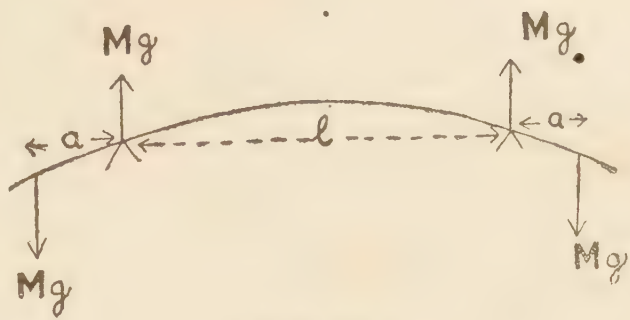


Fig. 48

Tabulate the readings as follows :—

- The beam used is a box-wood metre scale.

Distance between knife-edges (l) = 50 cms.

Distance between knife-edge and point } = 20 cms.
where load is applied (a)

Mean breadth of beam = 2.67 cms.

Mean height of beam = 0.45 cm.

Least count of vernier microscope = 0.001 cm.

Load applied	Reading			Load applied	Reading			Difference ($y_2 - y_1$)
	while adding	while removing	Mean (y_1)		while adding	while removing	Mean (y_2)	
grams.	cms.	cms.	cms.	grms.	cms.	cms.	cms.	cms.
0	2.620	2.621	2.621	250	3.304	3.310	3.307	0.686
50	2.760	2.760	2.760	300	3.442	3.444	3.443	0.683
100	2.899	2.900	2.900	350	3.573	3.575	3.574	0.674
150	3.034	3.035	3.035	400	3.704	3.710	3.707	0.672
200	3.167	3.168	3.168	450	3.844	3.844	3.844	0.676
Mean								0.674

$$q = \frac{3 Mg a l^2}{2 b d^3 y} = \frac{3 \times 250 \times 980 \times 20 \times 50^2}{2 \times 2.67 \times 0.45^3 \times 0.674} = 1.12 \times 10^{11} \text{ dynes/cm}^2.$$

$\therefore$ The Young's Modulus of the beam is 1.12×10^{11} dynes/cm².

Alter the distance between the knife-edges and the points where the loads are applied. Take two more sets of readings and tabulate similarly. Calculate q .

Graph :—A load-elevation graph is drawn, representing load along the X axis and elevation along the Y axis. The graph is a straight line.

(B) Single Optic Lever method

Aim :—To determine the Young's Modulus of Elasticity of a beam by uniform bending, using a single optic lever for measuring the elevations at the centre, when equal loads are applied at the ends, symmetrically.

Apparatus required :—A long, uniform, rectangular beam, an identical auxiliary beam. Two tall knife-edge supports, telescope and scale, a single optic lever, slotted weights.

Procedure :—Place the two beams on the knife-edge supports side by side, but not touching each other. Place the single optic lever on the beam, with the single leg resting at the centre of the experimental beam and the two hind legs on the auxiliary beam. Pass two loops of thick wire over the experimental beam, one at each end of it. Weight hangers can be hung from these loops. Keep them equidistant from the ends of the beam and from the knife-edges. Add equal weights to the weight hangers, one by one, and remove them, to train the beam to bend and unbend.

Place the stand with the telescope and scale in front of the mirror in the optic lever at a distance of about a metre from it. Adjust the scale to be vertical. Turn the telescope round and adjust its height so that its axis passes through the centre of the mirror.

Focus the telescope on the image of the scale seen in the mirror. Make the horizontal cross-wire coincide with a definite division in the scale.

Add gently two equal weights to the hangers at either end. The beam bends and the front leg of the optic lever is displaced upwards. Note the reading on the scale coinciding with the horizontal cross-wire. Add equal weights, one by one, till the maximum safe load is reached. Take the reading of the scale division coinciding with the horizontal cross-wire as each pair of weights is added. Remove the weights, one by one, and take the corresponding readings. Take about 8 to 10 readings.

Alter the length of the beam between the knife-edges and repeat the experiment.

Remove the beam and measure its breadth and height, accurately, at half a dozen places on it, spaced equally along its

length, with a vernier calipers or a screw gauge. Particular care is taken in measuring the height accurately.

Measure the perpendicular distance between the front leg in the optic lever and the line joining the hind legs by placing the optic lever on a paper and pressing it, so that the legs leave impressions on it. Measure also the distance between the scale and the mirror.

Calculations :—If a beam resting on two knife-edges is subjected to uniform bending, by applying equal loads at its ends, symmetrically, then, as explained in the previous experiment,

$$q = \frac{3 Mg a l^2}{2 b d^3 y}$$

Where, Mg = Load at each end,

l = Length between the knife-edges,

a = distance between each knife-edge and the point where the load is applied,

b = breadth of beam,

d = height of beam and

y = elevation at the centre of the beam, when Mg is applied at the ends.

Now, $y = \frac{s \times x}{2D}$

Where, s = displacement in the scale division.

x = perpendicular distance between the front leg and the plane passing through the hind legs.

D = distance between mirror and scale.

Tabulate the readings as follows :—

Distance between the knife-edges = 80 cms.

Distance between each knife-edge and the point where the load is applied } = 10 cms.

Distance between the scale and the mirror of the optic lever } = 76 cms.

Distance between the outer leg and the plane of the inner legs in the optic lever } = 8 cms.

Load at either end	Reading on Scale			Load at either end	Reading on Scale			Difference in reading s	Elevation $y = \frac{s \times x}{2D}$
	While adding	While removing	Mean		While adding	While removing	Mean		
grams.				grams.					cms.
0	25.0	24.9	25.0	2000	27.0	27.0	27.0	2.0	0.106
500	25.5	25.4	25.5	2500	27.5	27.5	27.5	2.0	0.106
1000	26.0	26.0	26.0	3000	28.0	28.0	28.0	2.0	0.106
1500	26.5	26.5	26.5	3500	28.5	28.5	28.5	2.0	0.106
Mean								2.0	0.106

Mean breadth of beam = 0.99 cms. }
Mean height of beam = 0.94 cms. }

$$\therefore q = \frac{3 \times 2000 \times 980 \times 10 \times 80^2}{2 \times 0.99 \times 0.94^3 \times 0.106}$$

$$= 21.59 \times 10^{11} \text{ dynes/sq. cm.}$$

$\therefore$ The Young's Modulus of Elasticity of the material (Steel) of the beam = 21.59×10^{11} dynes/cm².

Tabulate similarly for the other sets of readings taken.

Graph :—Draw a load-elevation graph, representing the load at either end along the X axis and the elevation along the Y axis. It will be a straight line.

EXPERIMENT 27

RIGIDITY MODULUS BY STATIC TORSION

Aim :—To determine the Rigidity Modulus of a cylindrical rod by Static Torsion.

Apparatus required :—Searle's Static Torsion apparatus, slotted weights.

(A) Scale and Pointer method

Description of apparatus :—The apparatus consists of a rigid frame work with a vertical support at the rear, at the centre of which is fixed a chuck. One end of the experimental rod R about 50 cms. in length is introduced into this chuck and firmly gripped. The other end of the rod is introduced into a similar chuck fitted to the centre of a circular wheel P, at the front of the apparatus. The wheel is about 10 cms. in diameter and has a broad rim

about 1 cm. in breadth. It is supported on smooth ball bearings at its centre. One end of a strong, flat tape is attached to a fixed

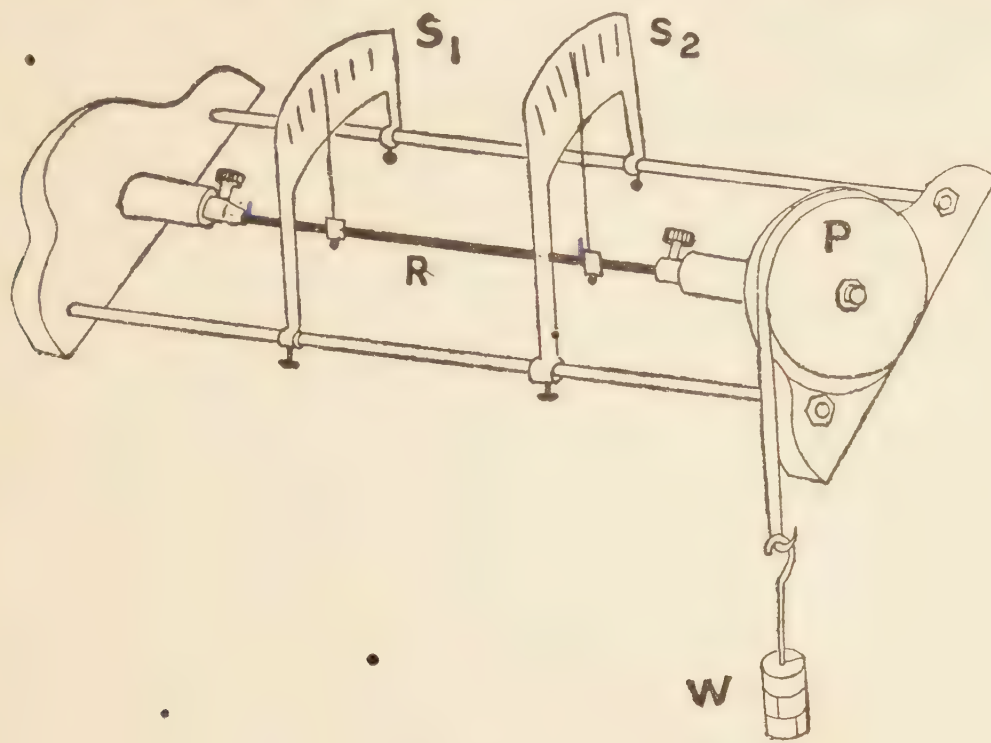


Fig. 49

nail on the rim of the wheel. It is wound once over the rim and at the free end a hook is attached to it. From the hook, a weight-hanger is suspended. When a weight W is added to the hanger, its moment about the centre of the wheel rotates it. The end of the rod fixed to the centre of the wheel gets twisted. The grip at either end of the rod must be so firm that there is no slipping when a couple is applied. Two cross rods connecting the front and rear of the apparatus at its base serve also as carriers of two circular scales S_1 and S_2 . Two vertical pointers are clamped on the experimental rod and their ends move over the scales. When the rod is twisted, the pointers move over the scales and the angles of twist can be read on the scale.

Procedure :—Clamp one of the scales and the pointer in front of it, very near the rear end of the rod. Clamp the other scale and pointer at a distance of about 30 to 40 cms. from the first. Adjust the pointers so that they are opposite to the zeros marked at the respective centres of the scales. Tighten the chucks so that the rod is firmly gripped. Perform a preliminary set of experiments in which the weights added to the weight hanger are increased one by one till the maximum safe load is reached. They are then removed one by one. The tape is passed over the rim in the opposite direction and the loading and unloading repeated. This is to train the rod to undergo torsion.

Then, starting with zero load, take the initial readings of the pointers. If the instrument is good and if there is no possibility of the slipping of the rod at the fixed end, the pointer near the fixed end can be dispensed with. This will make the experiment simpler. Add equal weights to the hanger, one by one at a time. Take the corresponding readings of the pointers. After the maximum safe load has been added and readings taken, remove the weights, one by one, and take readings. Take about 8 to 10 readings. The tape is wound over the wheel in the opposite direction. If the moment applied previously was clockwise, it will now be anti-clockwise and *vice versa*. Add and remove weights as before and take the readings of the pointers on the scales.

Alter the distance on the rod between the two pointers and repeat the experiment. Take readings for three or four different lengths of the rod.

Measure the diameter of the rod accurately, with a screw gauge, at not less than six places on it, equally spaced along its length. At each place, measure the diameter in two mutually perpendicular directions. Find the average diameter and calculate the radius. The diameter has to be measured very accurately, as the fourth power of the radius is involved in the calculations. Find the diameter of the circular wheel accurately, with a vernier calipers.

Calculations :—When a cylindrical rod is firmly clamped at one end and a couple applied at the other end, in a plane perpendicular to its length, it gets twisted. If l is the length of the rod, r its radius, θ the angle of twist in radian measure, C the moment of the couple, and n the modulus of rigidity of the material of the wire, then

$$C = \frac{\pi n r^4 \theta}{2l}$$

If the weight added is Mg and R is the distance between the centre of the rod and the line of action of the force, the moment of the couple = $Mg R$.

$$\therefore Mg R = \frac{\pi n r^4 \theta}{2l}$$

$$\text{or } n = \frac{2MgRl}{\pi r^4 \theta}$$

Divide the readings into two groups, to find the angle of twist for a particular load. Thus, find the difference in the angles of twist for 4 W and 0, 5 W and W, 6 W and 2 W, 7 W and 3 W. Their average will give the angle of twist for 4 W grams. Convert it into radian measure before applying it in the formula.

Tabulate the results as follows :—

Weight added grams	Reading of Pointer I on Scale				Reading of Pointer II on Scale				Angle of twist $\theta_2 - \theta_1$	Difference in the angle of twist	
	Moment clockwise		Moment anti-clockwise		Mean Reading θ_1	Moment clockwise		Moment anti-clockwise			Mean Reading θ_2
	While adding	While removing	While adding	While removing		While adding	While removing	While adding	While removing		
0 W 2 W 3 W 4 W 5 W 6 W 7 W	(1) L	length	of rod	= cms.							
0 W 2 W 3 W 4 W 5 W 6 W 7 W	(2) L	length	of rod	= cms.							

II. Diameter of rod

Pitch of Screw gauge = cms. ; Least count = cms.
Zero reading = cms. ; Zero correction = cms.

No.	Along one direction				Along a perpendicular direction			
	Pitch Scale	Head Scale	Zero correction	Corrected reading	Pitch Scale	Head Scale	Zero correction	Corrected reading
1								
2								
3								
4								
5								
6								
Mean					Mean			

∴ The mean diameter of rod = cms.
∴ The mean radius of rod = cms.

III. Mean diameter of wheel = cms.
Mean radius of wheel = cms.

Use these data and calculate n the modulus of rigidity of the material of the rod, from the formula,

$$n = \frac{2 \text{ Mg R} /}{\pi r^4 \theta}$$

(B) Telescope and Scale method

Procedure :—This is a more accurate method. Remove the scales and the pointers attached to the rod. Fix a small plane mirror (about 1.5 cms. square) to the rod, vertically, with some wax or with a metal clip fitted to the back of the mirror, at a distance of about 30 to 40 cms. from its fixed end. Set up the stand carrying the telescope and scale at a distance of about 100 cms. from the mirror. Turn the scale so that it is vertical. Rotate the telescope and adjust its height so that its axis passes through the centre of the mirror. Adjust the eye-piece so that the cross-wires are distinctly seen. Focus the telescope on the image of the scale seen in the mirror. Tilt it slightly so that the

intersection of the cross-wires coincides with a definite division on the scale. Note the reading. Proceed as in the previous experiment and take readings with the telescope, while adding and removing the weights. Take readings for both clockwise and anti-clockwise rotation. Alter the position of the mirror and take another set of readings. Measure carefully the mean diameter of the wheel with a vernier calipers and the mean diameter of the rod with a screw gauge.

Tabulate the readings as follows :—

I. Diameter of the rod

Pitch of screw gauge	=	1 mm.
Least count	=	0.01 mm.
Zero reading	=	+ 0.02 mm.
∴ Zero correction	=	— 0.02 mm.
Mean diameter of the rod	=	6.25 mm.
(Mean of six readings)		
∴ Mean radius	=	3.125 mm.
	=	0.3125 cm.

II. The mean diameter of the wheel = 12.4 cms.

∴ The mean radius of the wheel = 6.2 cms.

III. Length of rod = 30 cms.

Distance of scale from mirror = 80 cms.

Load in grams.	Clockwise moment				Anti-clockwise moment			
	Reading on Scale			Shift in scale reading for 800 gms.	Reading on Scale			Shift in scale reading for 800 gms.
	While adding	While removing	Mean		While adding	While removing	Mean	
grams.								
500	8.50	8.50	8.50		13.80	13.80	13.80	
700	7.50	7.45	7.48		14.80	14.80	14.80	
900	6.50	6.40	6.45		15.85	15.90	15.88	
1100	5.45	5.40	5.43		16.95	17.00	16.98	
1300	4.40	4.40	4.40	4.10	18.00	18.00	18.00	4.20
1500	3.35	3.35	3.35	4.13	19.10	19.10	19.10	4.30
1700	2.30	2.30	2.30	4.15	20.10	20.20	20.15	4.27
1900	1.30	1.30	1.30	4.13	21.20	21.20	21.20	4.22
			Mean	4.13			Mean	4.25

$\therefore$ Mean shift for a load of 800 grams = 4.19 cms.

$\therefore$ The mean angle of shift = $\frac{4.19}{2 \times 80} = \frac{4.19}{160}$ radians.

$$\begin{aligned}\therefore n &= \frac{2MgRl}{\pi r^4 \theta} \\ &= \frac{2 \times 800 \times 980 \times 6.2 \times 30 \times 160}{3.1416 \times 0.3125^4 \times 4.19} \\ &= 3.71 \times 10^{11} \text{ dynes per sq. cm.}\end{aligned}$$

The Modulus of Rigidity of the material of the rod (brass) is 3.71×10^{11} dynes/cm².

Tabulate the results for other sets of readings in a similar manner.

EXPERIMENT 28

RIGIDITY MODULUS BY TORSIONAL OSCILLATIONS

Aim :—To determine the Modulus of Rigidity of a wire by Torsional Oscillations.

Apparatus required :—Steel or brass wire, a uniform metallic disc (circular or rectangular), stop-watch.

Procedure :—The metallic disc has a chuck screwed at its centre. One end of the wire is introduced into the chuck and firmly gripped. The other end of the wire is passed through another chuck fitted in a wall bracket or held firmly in a retort clamp attached to a heavy retort stand. The length of the wire is adjusted for a definite value and the chuck tightened. Make a fine mark with a chalk on the side of the disc. Place a tall knitting needle in front of the disc, so that the needle is opposite to the mark. Compare the stop-watch with a standard clock, if available. Find out, if any correction has to be applied to its readings.



Fig. 50

Measure carefully with a beam compass the length of the suspension wire from the lower end of the top chuck to the upper end of the

chuck screwed into the disc. Standing in front of the torsion pendulum, gently twist the disc about its centre and let go, so that it makes rotational oscillations. The suspension wire and the disc must not oscillate laterally. Omit the first few oscillations and start the stop-watch when the mark on the disc passes across the equilibrium position as indicated by the knitting needle. When it passes across the mean position in the same direction again, it has executed one oscillation. Note the time taken for 15 to 20 oscillations. Take three such readings. Calculate the mean period. Alter the length of the wire by 10 cms. and note the time for 15 to 20 oscillations as before. Take three readings. Alter the length of the wire again and repeat. Take six such sets of readings. Calculate the mean period of oscillation in each case.

Measure the radius of the wire accurately, using a screw gauge. The diameter must be measured in half a dozen places, spaced equally along the wire and, at each place, in two mutually perpendicular directions. Particular care must be taken in the measurement of the radius, as its fourth power is involved in the calculations.

Remove the disc and find its mass. Measure its dimensions carefully, [diameter, if circular ; length and breadth, if rectangular] with a vernier calipers.

Calculations :—The period of oscillation T of a torsion pendulum is given by,

$$T = 2\pi \sqrt{\frac{I}{C}}$$

where C is the couple per unit twist and I is the moment of inertia of the disc. Now,

$$C = \frac{\pi n r^4}{2l}$$

where l is the length of the suspension wire, r , its radius, and n , its modulus of rigidity.

$$\therefore T = 2\pi \sqrt{\frac{I}{\frac{\pi n r^4}{2l}}} = 2\pi \sqrt{\frac{2lI}{\pi n r^4}}$$

$$\text{Squaring, } T^2 = \frac{4\pi^2 \times 2 l I}{\pi n r^4} = \frac{8\pi l I}{n r^4}$$

$$\therefore n = \frac{8\pi l I}{T^2 r^4}$$

Tabulate the results as follows :—Material of wire used is brass.

I. Period of oscillation

Length of Pendulum	Time for 20 oscillations			Period of oscillation	$\frac{l}{T^2}$
	I Reading	II Reading	Mean		
46.2 cms.	6' 27"	6' 26"	6' 26.5"	19.3"	0.124
51.1 "	6' 46"	6' 47"	6' 46.5"	20.3"	0.124
61.0 "	7' 22"	7' 23"	7' 22.5"	22.1"	0.125
67.2 "	7' 45"	7' 45"	7' 45"	23.3"	0.124
				Mean	0.124

The values in the last column will be constant, as l/T^2 is constant for the same wire and disc.

II. Radius of wire

Pitch of screw gauge	=	0.5 mm.
Least count	=	0.01 mm.
Zero reading	=	+ 0.06 mm.
Zero correction	=	— 0.06 m.m.
Average diameter of the wire	=	0.46 mm.
$\therefore$ Average radius of the wire	=	0.23 mm.

III. Mass of disc.	=	1001.5 gms
Average diameter of the disc	=	16.75 cms.
$\therefore$ Average radius of the disc	=	8.38 cms.

$$\text{Moment of Inertia of the disc, } I, = \frac{M R^2}{2}.$$

$$\therefore I = \frac{1001.5 \times 8.38^2}{2} = 35160 \text{ gm. cm}^2$$

$$\therefore n = \frac{8 \times 3.1416 \times 35160 \times 0.124}{(0.23)^4}$$

$$= 3.92 \times 10^{11} \text{ dynes/sq. cm.}$$

$\therefore$ The Modulus of Rigidity of the material of the brass wire is 3.92×10^{11} dynes per sq. cm.

EXPERIMENT 29

MOMENT OF INERTIA BY TORSIONAL
OSCILLATIONS

Aim :—To determine the Moment of Inertia of a disc by Torsional Oscillations and calculate the Modulus of Rigidity of the wire.

Apparatus required :—Steel or brass wire, a uniform metallic disc (circular or rectangular), two identical cylindrical masses, stop-watch.

Procedure :—One end of the wire is introduced into the chuck fitted at the centre of the disc and firmly gripped. The other end is passed through another chuck fitted to a wall bracket or held firmly in a retort clamp attached to a heavy retort stand as in the previous experiment. Adjust the length of the wire for a definite value and tighten the two chucks. Make a fine chalk mark on the side of the disc. Place a knitting needle in front of the disc, so that when you stand before the disc in a suitable position, the needle will hide the mark. Compare the stop-watch with a standard clock, if available, and find out if any correction is necessary.



Fig. 51

Measure carefully the length of the suspension wire, between the two chucks using a beam compass. Standing in front of the pendulum, gently set it in rotational oscillation, without any lateral movement. Omit the first few oscillations and note the time for 15 to 20 oscillations. Take two or three readings. Draw a line on the disc passing symmetrically through the centre. Place the two cylindrical masses, on the line drawn, one on either side of the central chuck and close to it. Set the pendulum to oscillate and note the time for 15 to 20 oscillations. Take two or three readings. Move the cylindrical masses along the line, about 5 cms. away from the centre, so that they are equidistant from it. Again note the time for 15 to 20 oscillations. Take two or three readings. Calculate the mean period of oscillation in each case.

Repeat the experiment for one or two more lengths of the wire.

• Measure carefully the diameter of the wire, at six different places, equally spaced along the length of the wire, with a screw gauge. At each place, the diameter must be measured along two mutually perpendicular directions.

Find the mean of the readings and calculate the radius. As the fourth power of the radius occurs in the formula, it must be measured with particular care. Find the mass of each of the cylinders with a balance.

Calculations :—Let T_1 be the period of oscillation of the pendulum alone, T_2 the period when the cylindrical masses are close to the centre and T_3 when they are at a distance from the centre. Let d_1 be the distance between the centre of the disc and the centre of either mass in the first position, and d_2 , the corresponding distance in the second position. .

Then,

$$T_1 = 2\pi \sqrt{\frac{I}{C}}$$

$$T_2 = 2\pi \sqrt{\frac{I + 2i_0 + 2md_1^2}{C}}$$

$$\text{and } T_3 = 2\pi \sqrt{\frac{I + 2i_0 + 2md_2^2}{C}}$$

where i_0 is the moment of inertia of each cylindrical mass about its centre.

$$\begin{aligned} \therefore T_3^2 - T_2^2 &= \frac{4\pi^2}{C} (2md_2^2 - 2md_1^2) \\ &= \frac{T_1^2}{I} (2md_2^2 - 2md_1^2) \end{aligned}$$

$$\therefore I = \frac{T_1^2 \times 2m \times (d_2^2 - d_1^2)}{T_3^2 - T_2^2}$$

Now, $n = \frac{8\pi l}{T_1^2 r^4}$. Substituting for $\frac{I}{T_1^2}$,

$$n = \frac{16\pi m l (d_2^2 - d_1^2)}{r^4 (T_3^2 - T_2^2)}$$

Tabulate the results as follows :—

I. The total mass of the cylinders used (2m) = 698.4 grams.

II. Radius of the wire

Pitch of the screw gauge = 0.1 cm.

Least count of the screw gauge = 0.001 cms.

Zero reading = -0.002 cms.

∴ Zero correction = +0.002 cms.

Average diameter of the wire
(Mean of six readings) = 0.0495 cms.

∴ Average radius of the wire = 0.0248 cms.

III. (1) Length of suspension wire = 72 cms.

Position of masses	Time for 10 oscillations			Period of oscillation secs.
	Reading I secs.	Reading II secs.	Mean secs.	
No mass	121	122	121.5	12.15
Masses at 3.8 cms. from centre ($d_1 = 3.8$ cms.)	144	144	144	14.40
Masses at 9.5 cms. from centre ($d_2 = 9.5$ cms.)	228	228	228	22.80

$$\therefore I = \frac{698.4 \times 12.15^2 \times (9.5^2 - 3.8^2)}{22.8^2 - 14.4^2}$$

$$= 25020 \text{ gm. cms.}^2$$

(2) Length of suspension wire = 58.8 cms.

Position of masses	Time for 10 oscillations			Period of oscillation secs.
	Reading I secs.	Reading II secs.	Mean secs.	
No mass	111	110	110.5	11.05
$d_1 = 3.8$ cms.	132	133	132.5	13.25
$d_2 = 9.5$ cms.	209	209	209	20.90

$$I = \frac{698.4 \times 11.05^2 \times (9.5^2 - 3.8^2)}{20.9^2 - 13.25^2}$$

$$= 24740 \text{ gm cm.}^2$$

$$\text{Average } I = 24880 ; \text{ Average } \frac{l}{T^2} = 0.485$$

$$\begin{aligned} \therefore n &= \frac{8 \times 3.1416 \times 24880 \times 0.485}{0.0248^4} \\ (\text{Steel}) &= 8.01 \times 10^{11} \text{ dynes/cm}^2 \end{aligned}$$

$\therefore$ The mean Modulus of Rigidity of the material of the wire
 $= 8.01 \times 10^{11} \text{ dynes/cm}^2$

Mean Moment of Inertia of the disc is 24880 gm cm.²

EXPERIMENT 30

q, n AND σ BY SEARLE'S METHOD

Aim:—To determine the Young's Modulus, Rigidity Modulus and Poisson's ratio for a wire by Searle's method.

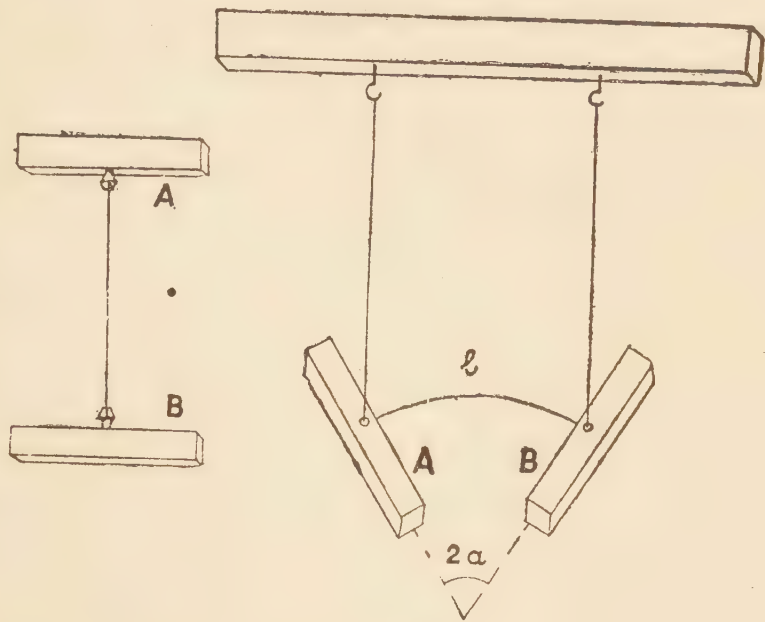
Apparatus required :—Searle's apparatus, stop watch.

Description of apparatus :—This apparatus consists of a pair of identical uniform bars A, B of steel or brass of circular or square cross-section. Their lengths are about 30 to 40 cms. and cross-section about 1 square cm. Each of the bars has a chuck screwed at its centre. The ends of the experimental wire about 30 cms. long are introduced into these chucks and tightly gripped. The bars are suspended from a rigid support by two strong strings of equal length. The strings are adjusted so that they are parallel and the bars lie in the same horizontal plane.

Procedure :—The two ends of the bars are brought together and let go. They then vibrate in a horizontal plane about their centre. This is effected by bringing the two ends close together, tying them by a light thread and then burning of the thread. The oscillations must be regular. The wire connecting them bends into an arc of a circle, on either side, when the bars oscillate and thus the oscillations are maintained. With the stop-watch find the time for 15 to 20 oscillations. Take three readings and find the mean. From this calculate the period of oscillation (T_1).

Then, clamp one of the bars at its centre tightly in a retort clamp fixed to a stand, so that the other bar hangs freely from

the suspension wire. Set the bar in torsional oscillation about its centre and note the time for 15 to 20 oscillations. Take three readings, find their mean and calculate the period of oscillation. Measure the length of the wire between the chucks carefully. Measure the radius of the wire accurately with a screw gauge, Measure the diameter in half a dozen places, spaced equally along the wire and in each place in two mutually perpendicular directions. As the fourth power of the radius is involved in the calculations, it has to be measured accurately.



Fig, 52

Calculations :—In the first experiment, the wire is bent into an arc of a circle. The bending moment = $\frac{qAK^2}{R}$. If the length of the wire is l , then $l = 2Ra$. So, $R = \frac{l}{2a}$.

$$\therefore \text{Bending moment} = \frac{qAK^2}{l} \times 2a.$$

The bending moment provides the restoring couple. The angular acceleration is $\frac{2qAK^2a}{Il}$. So, the oscillations are simple harmonic. The period of oscillation T_1 is given by,

$$T_1 = 2\pi \sqrt{\frac{Il}{2qAK^2}}$$

where I is the Moment of Inertia of either bar.

$$\text{Now, } AK^2 = \pi r^2 \times \frac{r^2}{4} = \frac{\pi r^4}{4}$$

$$\therefore T_1^2 = \frac{8\pi Il}{qr^4} \text{ or } q = \frac{8\pi Il}{T_1^2 r^4}$$

In the second experiment, the wire is subjected to torsional oscillations.

$$T_2 = 2\pi \sqrt{\frac{I}{C}} = 2\pi \sqrt{\frac{I}{\frac{\pi n r^4}{2l}}}$$

$$\therefore T_2^2 = \frac{8\pi I l}{n r^4} \text{ or } n = \frac{8\pi I l}{T_2^2 r^4}$$

$$\therefore \frac{q}{n} = \frac{8\pi I l}{T_1^2 r^4} \times \frac{T_2^2 r^4}{8\pi I l} = \frac{T_2^2}{T_1^2}$$

If I , the moment of inertia of the bar is calculated from its dimensions and mass, q and n can be calculated.

σ , the Poisson's ratio of the wire is calculated from the formula,

$$\sigma = \frac{q}{2n} - 1.$$

Tabulate the readings thus :—

Experiment I

Trial No.	Time for 15 oscillations	Period of oscillation T_1
-----------	--------------------------	--------------------------------

Experiment II

Trial No.	Time for 15 oscillations	Period of oscillation T_2
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Radius of wire :—

Pitch of screw gauge	=	cms.
Least count of screw gauge	=	cms.
Zero reading	=	cms.
Zero correction	=	cms.
Mean diameter of wire	=	cms.
(Mean of six readings)		
$\therefore$ Mean radius of wire	=	cms

Moment of Inertia of bar

Length of bar = cms.

Breadth (or height) of bar = cms.

Mass of bar = grams.

 $\therefore$ Moment of Inertia of bar =

$$\therefore q = \frac{8 \pi I l}{T_1^2 r^4} ; n = \frac{8 \pi I l}{T_2^2 r^4} \text{ and } \sigma = \frac{q}{2n} - 1$$

SECTION III**HEAT****EXPERIMENT 31****COEFFICIENT OF LINEAR EXPANSION OF A SOLID**

Aim :—To determine the coefficient of linear expansion of a solid using a single optic lever, telescope and scale.

Apparatus required :—Linear expansion apparatus, single optic lever, telescope and scale.

Description of apparatus :—The apparatus consists of a vertical wooden frame F about 50 cms. high, open in front and behind. At its centre stands vertically, a hollow brass jacket J suitably supported. It is tightly closed by rubber stoppers at the two ends. The experimental rod whose co-efficient of linear expansion is to be determined is inserted into the jacket, through the rubber corks, so that it projects above and below the jacket. The rod tapers to a point at the bottom end and rests on a small depression on a metallic plate. The top of the rod is flat and projects a little above the frame through a circular hole in it. A thick glass plate G with a central circular hole is placed on the frame with the rod passing through the hole. The top of the rod is flush with the surface of the glass plate. The brass jacket

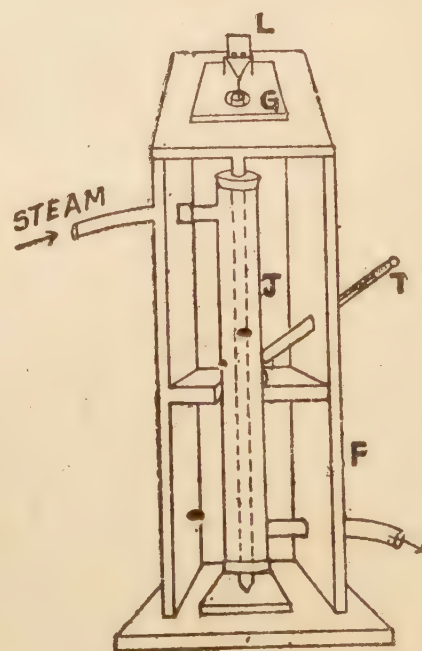


Fig. 53

has an inlet at the top for letting in steam and an outlet at its bottom for letting it off. Somewhere near the middle, there is another hole with a brass tube attached. This is closed with a cork and a thermometer T inserted through it.

The single optic lever L is placed on the glass plate at the top with its hind legs resting on the glass plate and its front leg resting on the flat top of the rod.

Procedure :—Place the telescope and scale in front of the apparatus. Turn the scale so that it is vertical and parallel to the mirror of the optic lever. Rotate the telescope so that its axis is horizontal and passes through the centre of the mirror. The distance between the mirror and the scale may be from 80 to 100 cms. Adjust the eye-piece of the telescope, so that its cross-wires are distinctly seen, one of them being horizontal and the other vertical. Gently tilt the telescope so that the horizontal cross-wire coincides with a definite division on the scale. Note the reading. If necessary, illuminate the scale with a lighted bulb.

Get ready a steam boiler. Connect the outlet tube in it, to the inlet at the top of the apparatus, using a long rubber tube. Pass the steam into the jacket. It will heat the rod and escape at the bottom. The rod will expand. The bottom end rests on a metallic plate. So, no expansion will take place at that end. All the expansion will be at the top. So, the front leg of the optic lever will move up. The mirror will get tilted and the reading on the scale will change.

Pass the steam for half an hour. Note the reading on the scale coinciding with the horizontal cross-wire. Take a reading after the steam had passed for another five or ten minutes. When three consecutive readings taken at intervals of five or ten minutes are the same, stop the supply of steam. Note the temperature of the steam.

Allow the jacket to cool. Remove the rod and measure its length carefully. Press the optic lever on a sheet of paper. Measure the distance between the front leg and the plane of the other two legs.

Tabulate the readings as follows :—

Initial reading on the scale	=	S_1
Final reading on the scale	=	S_2
Shift in reading	=	$S_2 - S_1$
Distance between the mirror and the scale	=	D cms.
Distance between the outer leg and the plane of the inner legs	=	d .

$$\therefore \text{Increase in length} = \frac{d \times (S_2 - S_1)}{2 D} = l \text{ cms.}$$

$$\text{Length of the rod} = L \text{ cms.}$$

$$\text{Initial temperature of the rod} = T_1^\circ\text{C}$$

$$\text{Final temperature of the rod} = T_2^\circ\text{C}$$

$$\therefore \text{Coefficient of linear expansion of the material of the rod} = \frac{l}{L \times (T_2 - T_1)}$$

Repeat the experiment and take one more set of readings.

Find the mean coefficient.

EXPERIMENT 32

COEFFICIENT OF APPARENT EXPANSION OF A LIQUID

Aim :—To determine the coefficient of apparent expansion of a liquid using (1) a specific gravity bottle and (2) a pykanometer.

Apparatus required :—Specific gravity bottle, pykanometer, liquid, constant temperature bath.

(A) Specific gravity bottle.

Procedure :—Find the weight of a clean, dry specific gravity bottle correct to three places of decimals. Keep the liquid whose coefficient of apparent expansion is required, in an open beaker for some time, so that it takes up the temperature of the room. Fill the specific gravity bottle with the liquid carefully. See that no air-bubbles are formed. Hold the specific gravity bottle in the folds of a towel so that your hands do not come in contact with the bottle and heat it. When the bottle is full, insert the

stopper gently. The excess liquid escapes through the hole in the stopper. Wipe the outside of the bottle clean. Make sure that there are no air-bubbles inside. Handle the bottle by the neck. Find the weight of the bottle with the liquid accurately. Suspend

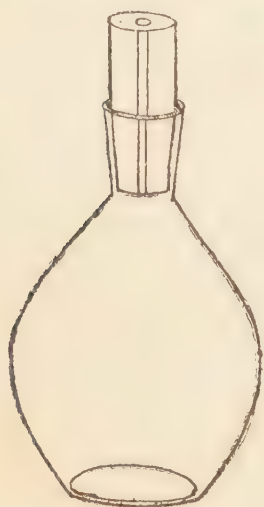


Fig. 54

the bottle in a constant temperature bath whose maximum temperature is far below the boiling temperature of the liquid. For ordinary liquids like kerosene oil, coconut oil etc., a water bath will do. The bottle should be so suspended in the liquid that the neck alone is above the surface the liquid in the bath.

Heat the bath. The liquid expands and oozes out through the hole in the stopper. Remove the escaping liquid with bits of filter paper, so that it does not mix with the liquid in the bath. When no more liquid escapes through the hole, the expansion may be taken to be complete. Remove the bottle and wipe its outer surface clean. Allow it to cool and then find its weight accurately.

To make sure that the expansion is complete, keep it in the bath for ten minutes more, remove it and find its weight. See if the two weights are the same.

Note the maximum temperature reached in the bath.

Tabulate the readings as follows :—

Weight of the specific gravity bottle $= W_1$ grams

Weight of the specific gravity bottle + the liquid filling the bottle $\} = W_2$ grams

$\therefore$ Weight of liquid alone filling the bottle $= (W_2 - W_1)$ grams

Weight of the specific gravity bottle + the liquid remaining in it after expansion is complete $\} = W_3$ grams

$\therefore$ Weight of liquid remaining in the bottle after expansion is complete $\} = (W_3 - W_1)$ grams

Temperature of the room at the time that the bottle is filled $\} = T_1^\circ\text{C.}$

Maximum temperature of the bath $= T_2^\circ\text{C.}$

If d is the density of the liquid at the room temperature, a volume of liquid $\left(\frac{W_3 - W_1}{d}\right)$ at temperature $T_1^\circ\text{C}$ expands, when

heated and occupies a volume equal to $\left(\frac{W_2 - W_1}{d}\right)$ at $T_2^\circ\text{C}$.

$$\therefore \left. \begin{array}{l} \text{Coefficient of apparent} \\ \text{expansion of the} \\ \text{liquid} \end{array} \right\} = \frac{\left(\frac{W_2 - W_1}{d}\right) - \left(\frac{W_3 - W_1}{d}\right)}{\left(\frac{W_3 - W_1}{d}\right) \times (T_2 - T_1)}$$

$$= \frac{(W_2 - W_3)}{(W_3 - W_1)(T_2 - T_1)}$$

$$\left. \begin{array}{l} \text{The coefficient of} \\ \text{absolute expansion} \\ \text{of the liquid.} \end{array} \right\} = \left. \begin{array}{l} \text{Its coefficient of} \\ \text{apparent expansion} \end{array} \right\} + \left. \begin{array}{l} \text{Coefficient of} \\ \text{volume expansion} \\ \text{of the} \\ \text{containing} \\ \text{vessel.} \end{array} \right\}$$

Repeat the experiment and take one more set of observations.

(B) Pykanometer

Description :—The Pykanometer is a small glass vessel specially designed for the determination of the coefficient of volume expansion of liquids. It has the shape shown in the figure. The body of it is an elongated cylindrical bulb about 10 cms. long and 1 cm. in diameter. To its top end, a glass tube bent at right angles is joined. At the bottom, is joined another similar glass tube, which is bent round so as to be parallel to the cylindrical bulb. At the top, the tube is bent at right angles along the same line as the other limb, but, in the opposite direction. The end of the tube is tapered. A mark M is made near the mouth of the tube attached to the top of the bulb. The liquid is always made to occupy the volume from this mark M to the mouth of the tapering tube at the other end.

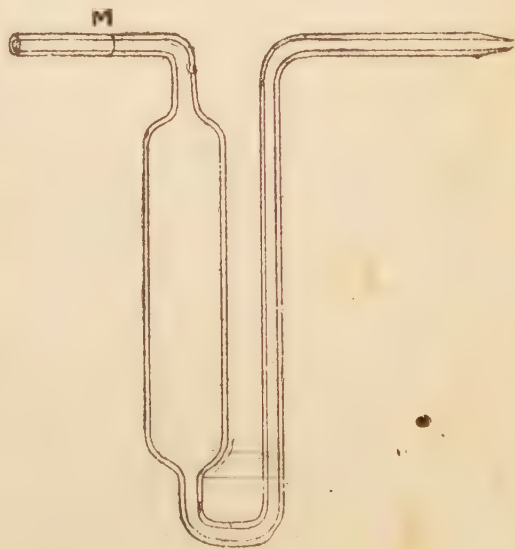


Fig. 55

Procedure :—Clean the pykanometer and dry it. Find its weight correct to three places of decimals. Attach a small length of rubber tube to the tapering end. Dip the mouth of the other

tube in the liquid kept in an open beaker. Suck up the liquid, till it fills the bulb and the tube up to the rubber tube. Take it out. Remove the liquid from its mouth carefully with bits of filter paper, so that the liquid occupies the volume from the fixed mark M, to the mouth of the tapering tube.

A wire is tied to the two limbs, so that the pykanometer can be suspended, with the two limbs in a horizontal position. Wipe its surface clean. Suspend the pykanometer from the stirrup in the balance and find its weight accurately.

Place the pykanometer in a water bath, immersing it in the water and resting its two limbs on the rim of the bath. As much of it as possible must be inside the water. Heat it. The liquid expands. Remove the liquid that escapes due to expansion, with bits of filter paper. When the maximum temperature of the bath is steady for some time and the expansion is complete, remove the liquid from the mouth of the tube carefully, with a bit of filter paper so that the liquid occupies the volume from the fixed mark M, to the mouth of the tapering end.

Remove the pykanometer, cool it and weigh it. Again suspend it in the water bath and keep it there for ten minutes. This is to make sure that the expansion is complete. Remove it and weigh again. Note the maximum temperature attained by the bath.

Tabulate the results as follows :—

Weight of pykanometer = W_1 grams

Weight of pykanometer + liquid } = W_2 grams
filling it

Weight of pykanometer + liquid } = W_3 grams
left after expansion is complete

Temperature of the room at the } = $T_1^\circ\text{C.}$
beginning of the experiment

Maximum temperature of the } = $T_2^\circ\text{C.}$
bath

$\therefore$ Coefficient of apparent } = $\frac{(W_2 - W_3)}{(W_1 - W_3) \times (T_2 - T_1)}$
expansion of the }
liquid

The coefficient } The coefficient } Coefficient of volume }
of absolute } of apparent } expansion of con- }
expansion } expansion } taining vessel }

Repeat the experiment and take another set of observations.

EXPERIMENT 33

COEFFICIENT OF INCREASE OF PRESSURE OF AIR AT CONSTANT VOLUME

Aim :—To determine the coefficient of increase of pressure of air at constant volume.

Apparatus required :—Pressure coefficient apparatus.

Description :—The pressure coefficient apparatus, also known as Joly's bulb apparatus, is a modified form of Boyle's Law apparatus. The closed tube is replaced by a Joly's bulb J, which is a spherical bulb about 5 to 6 cms. in diameter with a capillary tube leading from it. The tube is bent twice at right angles and inserted into the rubber tube containing mercury. There is a fixed mark M made on the tube, a little above the rubber tube. Mercury standing upto this mark encloses a definite volume of air in the Joly's bulb. The air in the bulb must be *perfectly dry*. To ensure this, a few drops of concentrated sulphuric acid are kept in it.

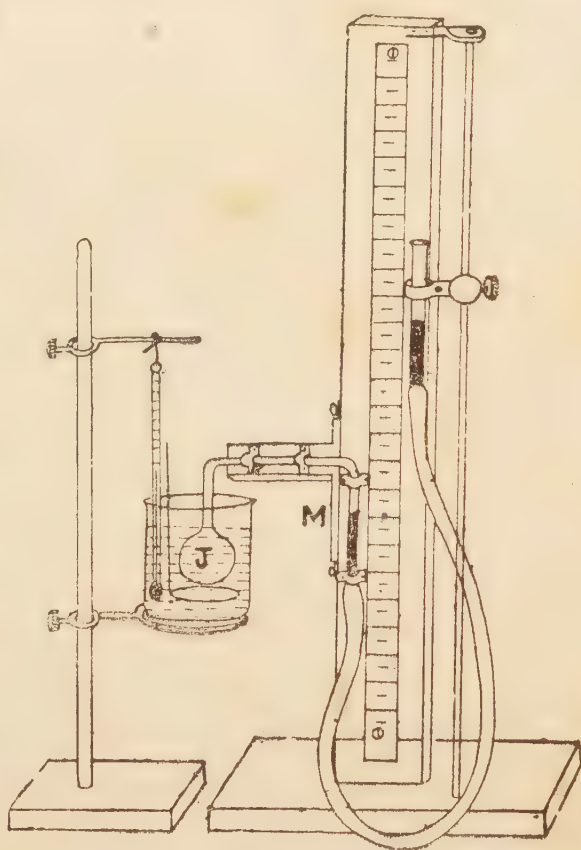


Fig. 56

Procedure :—Read the atmospheric pressure from the Fortin's Barometer, after making the preliminary adjustments. It is then standardised. Keep a beaker of water on a ring stand and bring it under the Joly's bulb, so that it is completely immersed in water. Place a thermometer in the water and note the temperature. Adjust the open tube on the right hand side in the apparatus, so that mercury stands at the fixed mark M on the tube on the left hand side. Note the two mercury levels and find their difference. The atmospheric pressure $\pm$ this difference (*plus*, if the mercury level on the right is above the fixed mark M and *minus*, if it is below) gives the pressure of the dry air in the bulb.

Heat the beaker with a small flame from the bunsen burner, so that the heating is slow and regular. Stir the water all the time to ensure uniform heating. When the temperature reaches 40°C , stir the water and regulate the heating so that the temperature remains constant for about 3 minutes. Adjust the height of the open tube on the right so that the mercury stands at the mark M on the left. Note the reading of mercury level in the open tube. Resume the heating till the temperature reaches 50°C . Maintain the temperature constant for 3 minutes. Adjust the height of the open tube so that the mercury stands at the fixed mark M. Note the reading of the mercury level. Heat again. Maintain the temperature constant at 60° , 70° , 80° , 90° . Adjust the height of the open tube in each case so that the mercury level stands at M and note the readings. Take the reading likewise at the boiling point. Remove the flame and allow the bath to cool. [As a precautionary measure, lower the open tube on the right sufficiently. Otherwise, as the temperature falls, the pressure of air in the Joly's bulb will decrease. There is then the risk of mercury entering the Joly's bulb and spoiling the experiment.] At temperatures 90° , 80° , 70° , 60° , 50° , 40° , maintain them constant for 3 minutes. Adjust the height of the open tube to make the mercury always stand at the fixed mark M. Note the corresponding readings of the mercury level in the open tube. To cool the water in the bath you may add small quantities of cold water carefully and stir the bath constantly. This will save time. Take a reading at the room temperature also.

Calculations :—Let P_2 be the pressure of dry air at a temperature $T_2^{\circ}\text{C}$ and P_1 the pressure at a temperature $T_1^{\circ}\text{C}$. If a is the pressure coefficient of air and P_0 the pressure at 0°C , then

$$P_2 = P_0 (1 + a T_2)$$

$$P_1 = P_0 (1 + a T_1)$$

$$\therefore \frac{P_2}{P_1} = \frac{P_0 (1 + a T_2)}{P_0 (1 + a T_1)} = \frac{1 + a T_2}{1 + a T_1}$$

$$\therefore a = \frac{P_2 - P_1}{P_1 \times T_2 - P_2 \times T_1}$$

20 to 25 cms. from one end of the tube, seal off that end. A column of dry air gets enclosed between the mercury thread and the closed end.

Fasten the capillary tube along with a thermometer on a half-metre scale. Immerse them vertically in a water bath, with the open end of the tube above and the mercury thread about 6 or 7 cms. below the level of the water in bath.

Note the initial length of the air column with the help of the metre scale. Heat the water bath slowly till the temperature rises to (40°C.) Stir the water well, regulate the heating and keep the temperature constant for not less than 15 minutes. Note the length of the air column and the corresponding temperature. [As the glass capillary tube is a bad conductor and is also thick walled, the temperature of the bath must be kept constant for a fairly long time to ensure that the air inside is heated to the temperature of the bath.] Heat the water bath to 50°C, 60°C, 70°C, 80°C, 90°C and the boiling point. At each temperature, keep it constant for not less than 15 minutes and note the lengths of the air column and the corresponding temperatures.

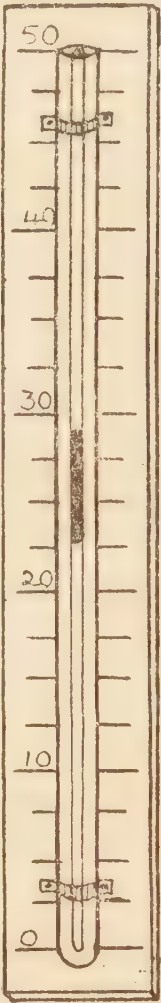


Fig. 61

Then, cool the water bath and at the temperatures mentioned above, note the lengths of the air column. Take care that the temperature is kept constant at each temperature as indicated above.

The pressure of the air inside is constant and is always equal to the atmospheric pressure *plus* the length of mercury thread.

Tabulate the results as follows :—

Temperature of bath 1	Reading of closed end of tube	Reading of lower level of Mercury			Length of air column 1	$\frac{l_2 - l_1}{l_1 \times T_2 - l_2 \times T_1}$
		While heating	While cooling	Mean		

For the entries in the last column, take the lengths of the air column at the room temperature and 70°, 40° and 80°, 50° and

90°, 60° and the boiling temperature and calculate a . Find the mean value of a .

Graph :—Draw a graph, plotting temperature along the X axis and the length of the air column long the Y axis. You will get a straight line graph. Produce it both ways and find the lengths of the air column at 0° and 100°. Calculate a .

$$a = \frac{l_{100} - l_0}{l_0 \times 100}$$

Use the graph, to find (1) the melting point of paraffin or naphthalene and (2) the boiling point of a liquid like alcohol. The lengths of the air column are determined corresponding to those temperatures and the temperatures are read off from the graph, as explained in Experiment 33, for the constant volume air thermometer.

EXPERIMENT 35

SPECIFIC HEATS OF SOLIDS AND LIQUIDS

Aim :—To determine accurately the specific heats of (1) a solid and (2) a liquid, by the method of mixtures.

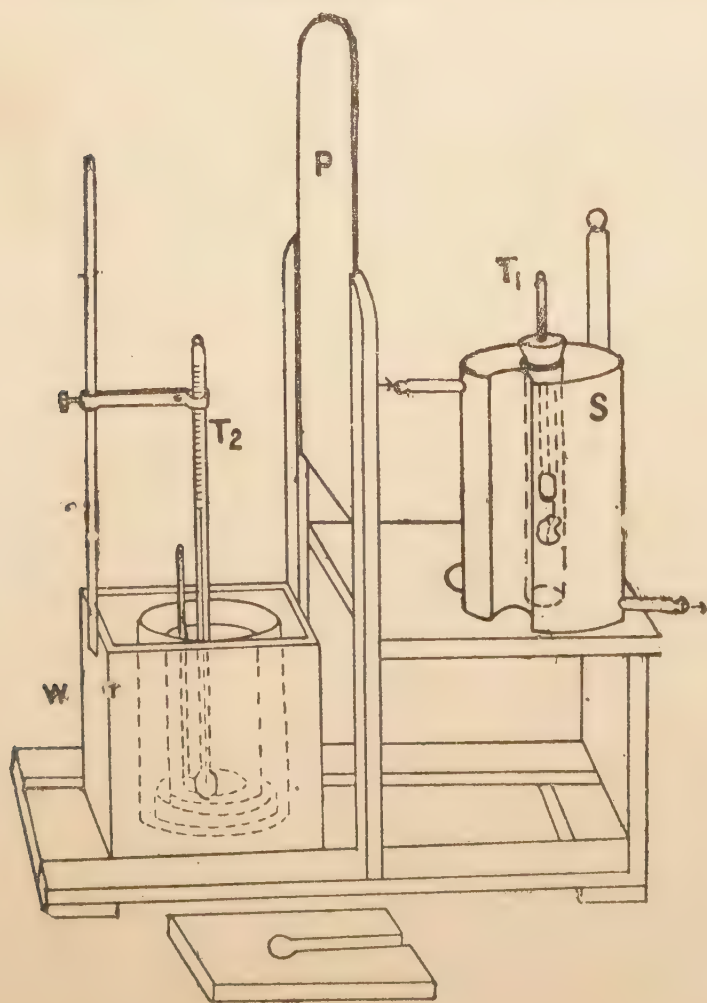


Fig. 62

Apparatus required :—Specific Heat apparatus, sensitive thermometer, solid, liquid.

Description of apparatus :—A compact apparatus, designed by Glazebrook and Shaw, is used for the experiment. It consists mainly of (1) an arrangement for heating the solid and (2) a calorimeter for receiving the solid and mixing it with water or liquid for transfer of heat. The two parts are kept on either side of a wooden

partition P, that can be raised or lowered when required.

The heating arrangement is a cylindrical steam heater S with a central air chamber about 3 to 5 cms in diameter, running from top to bottom. The hole is large enough for a solid to be suspended in it. The heater has an inlet at the top for letting in steam and an outlet at the bottom for the steam to escape. The circulation of steam outside the central chamber raises its temperature and the solid suspended in it gets heated. Since the steam does not come in contact with the solid, no condensation of steam can take place on it. The top of the air chamber is closed by a rubber cork through which a thermometer T_1 is inserted for noting the temperature of the solid, as it gets heated. The steam heater rests on a platform with a large circular hole at its centre. The steam heater is connected to a vertical rod on one side of the platform about which it can swing.

The calorimeter portion of the apparatus consists of an inner copper calorimeter resting on a non-conducting material like cork (or suspended) in an outer copper calorimeter. This is kept in a wooden box W. The box can slide smoothly on the base and, when the partition is raised, can be brought vertically under the hole in the platform on the other side. The calorimeter is provided with a stirrer. A bracket attached to the wooden box with a clamp in it carries a sensitive specific heat thermometer T_2 . The outer surface of the inner calorimeter and the inner surface of the outer calorimeter are brightly polished so as to minimise heat losses due to radiation.

[The above apparatus is only a compact form of apparatus used for the purpose. The experiment can, however, be performed, even if the above apparatus is not available as such. A separate steam-heater similar to the one described above and mounted on a retort stand can be used for heating the solid out of contact with steam. A separate calorimeter similar to the one described can be used for receiving the hot solid.]

(A) Specific Heat of a Solid

Procedure :—Tie the solid to a string and suspend it in the central chamber of the steam heater. Take out the other end of the string and tie it to the rod on the platform. Close the hole at the top by a rubber stopper. An ordinary thermometer is inserted through it, so that its bulb is by the side of the solid. Swing the heater to one side of the platform so that the bottom hole is

covered by it. Set up a steam boiler a little away from the apparatus and connect it to the tube at the top of the steam heater. Heat the boiler.

Remove the inner calorimeter with the stirrer and find its weight. Fill it with enough water to immerse the solid and again find the weight. Gently replace the calorimeter into the outer calorimeter. Insert the sensitive thermometer into the clamp, so that its bulb is well immersed in the water.

Allow the steam to circulate in the steam heater for about 30 to 45 minutes. Note the reading of the thermometer in the heater. Wait till the temperature (of the solid) is steady for over 15 minutes. Stir the water in the calorimeter and note the initial temperature. Have a stop-watch ready. Raise the partition, push the wooden box under the platform, swing the steam heater round so that the central chamber is above the hole in the platform, remove the rubber stopper, gently drop the solid into the calorimeter, start the stop-watch, push the box back to its original place and lower the partition. [All the above manipulations must be done as quickly as possible and without hitch. The solid must be dropped gently, so that the water does not splash.]

Stir the water well and note the temperature in the thermometer every half minute. It must be continued, even after the maximum temperature is reached, at least for an equal interval of time. With good conductors like copper, the maximum temperature will be reached quickly, while with solids like rubber, glass, etc. it will take some time. Take readings till the temperature falls by about 1 or 2 degrees after reaching the maximum.

Remove the inner calorimeter and stirrer when it has cooled and find the weight again. From this and the previous weight, the weight of the solid can be found.

Radiation correction :—The most important source of error is the cooling due to radiation, that takes place, while heat is being transferred from the solid to the water. A correction has to be applied for it. A simple correction is as follows. Note the time taken for the temperature of the calorimeter to reach the maximum. From the readings, find the fall of temperature during half the above interval of time, after the maximum temperature is reached. This is the radiation correction. It is known as the *half-time* correction. Alternatively, if the time taken for the rise

of temperature is very short, note the fall of temperature during an interval of time, equal to that taken for the rise of temperature. Half this fall of temperature is taken as the cooling correction. Both these are approximate and assume that the rise of temperature is uniform.

An accurate correction for radiation can be found by Barton's method. Draw a graph representing temperature on the Y axis and time on the X axis. The curve will have the shape

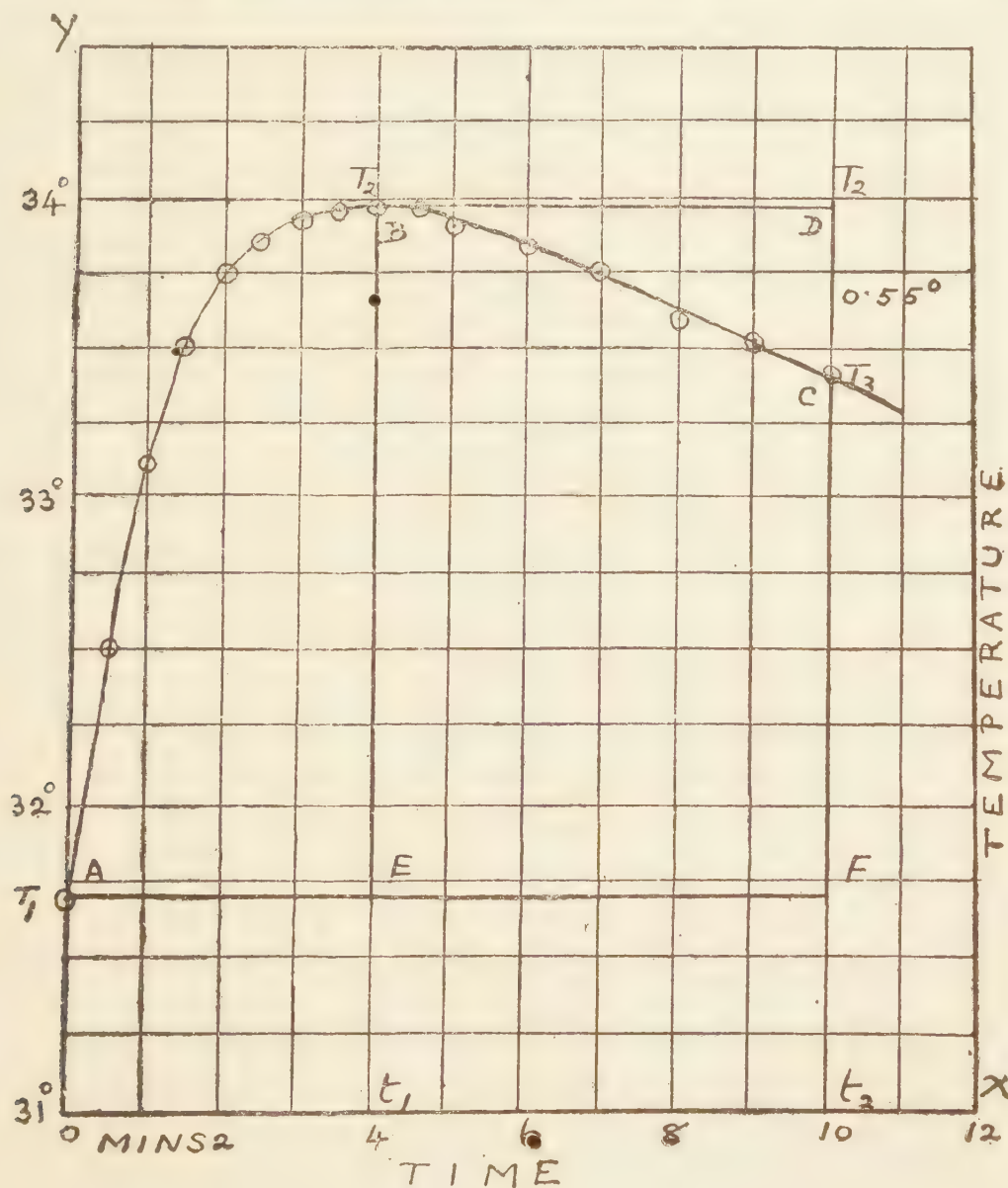


Fig. 63

shown in the figure. T_1 represents the initial temperature of the calorimeter and contents. T_2 represents the maximum temperature reached in time t_1 seconds. T_3 represents the temperature after t_2 seconds.

Let A correspond to T_1 , the initial temperature. It is also the temperature of the enclosure. Draw a line AEF parallel to the X axis. From B, corresponding to the maximum temperature T_2 , draw a line BE parallel to the Y axis and a line BD parallel to the

X axis. Through C which corresponds to T_3 draw a line D C F parallel to the Y axis.

Now the fall of temperature (i.e. cooling) in time $(t_2 - t_1)$ seconds is $(T_2 - T_3)$. Measure from the graph the areas of B C F E and A B E. The radiation correction i.e., the fall of temperature during t_1 seconds from the beginning, due to radiation is given by,

$$dT = \frac{\text{Area A B E}}{\text{Area B C F E}} \times (T_2 - T_3)$$

dT added to T_2 will give the temperature that would have been reached by the calorimeter and contents, if there had been no cooling due to radiation.

Calculations :—

Weight of calorimeter and stirrer	=	W_1 grams.
Weight of calorimeter, stirrer and water	=	W_2 grams.
∴ Weight of water alone	=	$(W_2 - W_1)$ grams.
Weight of calorimeter, stirrer, water and solid	=	W_3 grams.
∴ Weight of solid	=	$(W_3 - W_2)$ grams.
Initial temperature of water	=	$T_1^\circ\text{C}.$
Final maximum temperature of water after solid is added	=	$T_2^\circ\text{C}.$
Time taken for the maximum temperature T_2 to be reached	=	t_1 seconds.
Time taken for the temperature T_3 to be reached	=	t_2 seconds.
Radiation correction from graph	=	$dT.$
∴ Corrected final temperature	=	$(T_2 + dT)^\circ\text{C}$
Initial temperature of solid before it is dropped into the calorimeter	=	$T^\circ\text{C}.$
Specific heat of the material of the calorimeter	=	s

Let S be the specific heat of the solid.

Then, Heat lost = Heat gained.

$$\begin{aligned} \therefore (W_3 - W_2) \times S \times (T - T_2) \\ = \{W_1 s + (W_2 - W_1)\} \times \{(T_2 + dT - T_1)\} \\ \therefore S = \frac{\{W_1 s + (W_2 - W_1)\} \{(T_2 + dT - T_1)\}}{(W_3 - W_2) (T - T_2)} \end{aligned}$$

From this S is calculated.

Tabulate the readings as follows:—

I Balance Readings.

Object weighed	Weight on Right hand pan	Turning points		Resting point	Weight correct to a centigram
		Left	Right		
Zero load	Zero	7.5 9.0 10.0	13.0 11.5	10.5	
Calorimeter and stirrer	97.30 grams.	9.0 9.5 10.5	12.5 11.5	10.8	97.30 grams.
„	97.31 grams.	7.0 9.0 9.5	11.5 11.0	9.9	
Calorimeter, stirrer and water	179.14 grams.	9.5 10.0 10.5	13.5 13.0	11.6	179.15 grams.
„	179.15 grams.	6.5 7.5 8.0	14.0 13.0	10.4	
Calorimeter, stirrer, water and solid	196.25 grams.	7.5 9.0 10.0	12.5 11.5	10.3	196.25 grams.
„	196.24 grams.	8.5 10.0 11.0	14.5 13.0	11.8	

∴ Weight of calorimeter and stirrer = 97.30 grams.

Weight of water taken = 81.85 grams.

Weight of solid taken = 17.10 grams.

[For this experiment, it is enough, if the weights are taken correct to the centigram.]

Time-Temperature readings.

Time in minutes	Temperature	Time in minutes	Temperature	Time in minutes	Temperature
0	31.7°	4	33.95	8	33.6
$\frac{1}{2}$	32.5°	$4\frac{1}{2}$	33.95	$8\frac{1}{2}$	33.55
1	33.1°	5	33.9	9	33.5
$1\frac{1}{2}$	33.5°	$5\frac{1}{2}$	33.9	$9\frac{1}{2}$	33.5
2	33.75°	6	33.85	10	33.45
$2\frac{1}{2}$	33.85°	$6\frac{1}{2}$	33.8	$10\frac{1}{2}$	33.4
3	33.90°	7	33.75	11	33.4
$3\frac{1}{2}$	33.95°	$7\frac{1}{2}$	33.7	$11\frac{1}{2}$	33.35

Maximum temperature reached = 33.95°C

Radiation correction from graph }
applying Barton's method } = 0.31°C

∴ Corrected temperature = 34.26°C

Initial temperature of solid = 99°C

$$S = \frac{(9.73 + 81.85)(34.26 - 31.7)}{17.1 \times 65.05}$$

$$= \frac{91.586 \times 2.56}{17.1 \times 65.05} = 0.21$$

The solid is Aluminum.

(B) Specific Heat of a liquid using a solid of known Specific Heat

Procedure :—Select a solid which is neither soluble in the liquid nor chemically acted on by it. Determine its specific heat by the above method. Suspend it in the steam heater and pass steam.

Weigh the calorimeter and stirrer empty. Fill it with enough liquid to completely immerse the solid and weigh again.

Heat the solid sufficiently long so that the maximum temperature reached by it is steady for over 15 minutes. Note the temperature of the calorimeter and contents. Following the instructions given in the previous experiment, gently drop the solid into the calorimeter. Note the maximum temperature reached. Allow it to cool for some time and note the readings. Draw the temperature-time graph and find the radiation correction: Let S_1 be the specific heat of the liquid.

Calculations:—Using the same symbols as in the previous experiment,

Heat lost = $(W_3 - W_2) \times S \times (T - T_2)$

Heat gained = $\{W_1 s + (W_2 - W_1) S_1\} \{(T_2 + dT) - T_1\}$

$\therefore S_1 = \frac{(W_3 - W_2) \times S \times (T - T_2) - W_1 s (T_2 + dT - T_1)}{(W_2 - W_1) (T_2 + dT - T_1)}$

Tabulate the results as follows :—

I. Balance readings

Object weighed	Weights on Right hand pan	Turning points		Resting point	Weight correct to a centigram
		Left	Right		
Zero load	Zero	9.0	10.0	9.5	
		9.0	10.0		
		9.0			
Calori-meter and stirrer	47.59 gms.	9.5	10.5	10.0	47.60 grams.
		9.5	10.5		
		9.5			
	47.60 „	8.0	10	9.0	
		8.0	10		
		8.0			
Calori-meter + stirrer + liquid	140.54 „	9.0	10.5	9.8	140.54 grams.
		9.0	10.5		
		9.0			
	140.55 „	8.0	10.0	9.0	
		8.0	10.0		
		8.0			
Calori-meter + stirrer + liquid + solid	156.00 grams.	9.5	10.5	10.0	156.01 grams.
		9.5	10.5		
		9.5			
	156.01 grams.	9.0	10.0	9.5	
		9.0	10.0		
		9.0			

Weight of calorimeter and stirrer	=	47.60 grams.
Weight of liquid taken	=	92.95 „
Weight of solid	=	15.47 „

[In this experiment, it is enough if the weights are taken correct to a centigram.]

II. Time-Temperature readings :—

Time in minutes	Temperature	Time in minutes	Temperature
0	32.9°	2.0	37.1°
0.25	37.7°	2.5	36.9°
0.5	37.6°	3.0	36.8°
1.0	37.5°	3.5	36.7°
1.5	37.2°	4.5	36.6°

Maximum temperature reached = 37.7°C.

Radiation correction from graph = 0.05°C.

∴ Corrected temperature = 37.75°C.

∴ Rise of temperature of liquid = 4.85°C.

Initial temperature of solid = 96.5°C.

Specific heat of the solid (aluminium) = 0.22

$$\begin{aligned}\therefore S_1 &= \frac{15.47 \times 0.22 \times 58.8 - 4.76 \times 4.85}{92.95 \times 4.85} \\ &= 0.39\end{aligned}$$

∴ The specific heat of the liquid is 0.39.

EXPERIMENT 36

LATENT HEAT OF FUSION OF ICE

Aim :—To determine the Latent Heat of Fusion of Ice.

Apparatus required :—Calorimeter, Ice, Filter paper.

Description :—The calorimeter used for this experiment has a brightly, polished outer surface. It is suspended inside an outer calorimeter (or placed on a block of wood or cork kept at the

bottom of an outer calorimeter). It is provided with a special stirrer, covered with copper wire-gauze.

(A) Latent heat of fusion of ice

Procedure :—Find the weight of the inner calorimeter and stirrer correct to a centigram. Fill it with water to about two-thirds of its height and find the weight again. Suspend it carefully inside the outer calorimeter. Place a sensitive specific heat thermometer in it. Stir the water well and note its initial temperature. Take a small bit of ice, dry it well in the folds of a filter paper and drop it into the calorimeter, starting a stop-clock simultaneously. The drier the ice, the more accurate the result will be. Stir the water well. The ice must not be allowed to float up. Keep it always under water with the wire-gauze covered stirrer. After the ice has melted, add a few more bits similarly dried, one by one. The temperature will fall as the ice melts. Note the temperature every 15 or 30 seconds. When the temperature has fallen by 3 to 5° C, stop adding ice. Stir the water well and note the minimum temperature reached. Then allow it to raise in temperature by absorbing heat from outside. Continue noting the temperature every 15 to 30 seconds, till the temperature rises by about 1 or 2° C. Remove the inner calorimeter with the stirrer and find the weight again. The difference between this weight and the previous one will give the weight of ice added.

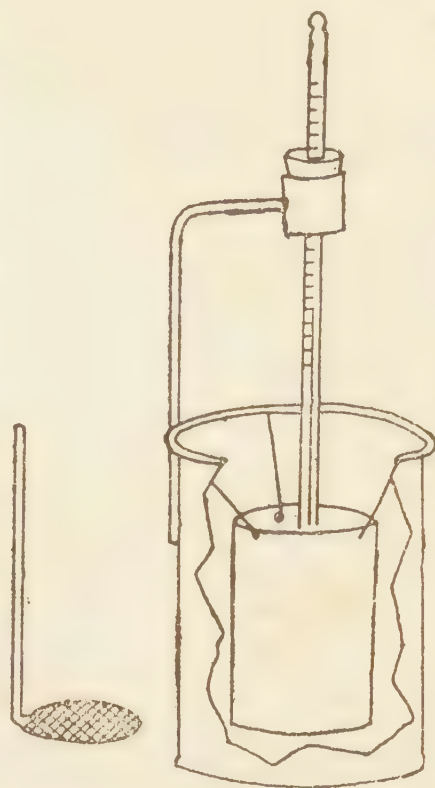


Fig. 64

Note :—Take care to see that the fall of temperature is not large enough to make the temperature of the calorimeter reach the dew-point. If that happens, dew will get deposited on the outer surface of the calorimeter and this will ruin the experiment.

Absorption correction :—In this experiment, heat is absorbed by the calorimeter as it cools. So, the temperature does not fall as it should. Hence, an absorption correction has to be applied to the final temperature.

An approximate correction is as follows. Note the time taken for the fall of temperature. Find the rise of temperature in

half that time, after the final temperature has been reached *or* half the rise of temperature during an equal interval of time, after the

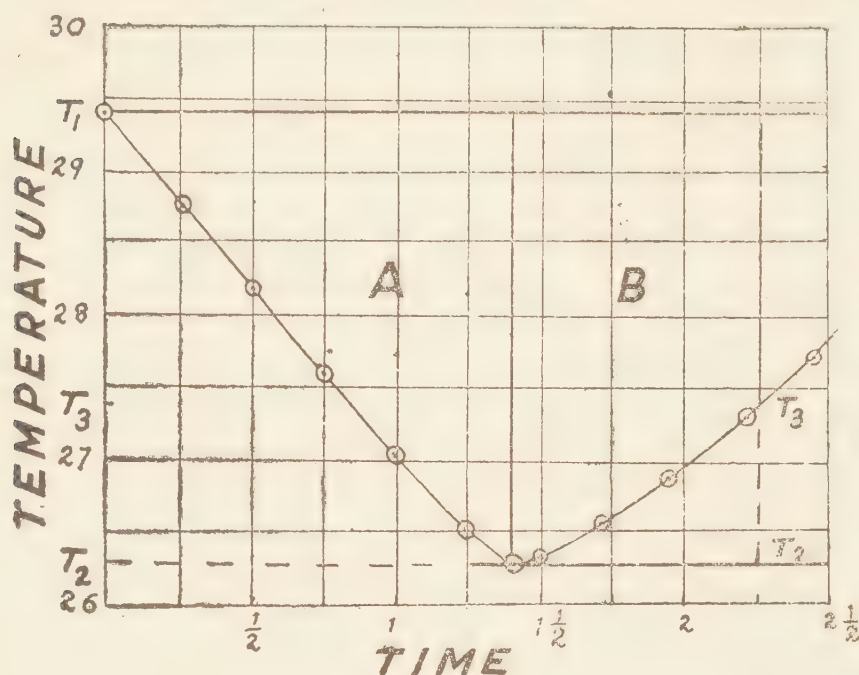


Fig. 65

final temperature has been reached. Subtract this from the final temperature noted. The corrected temperature will represent the temperature that would have been reached, if there had been no absorption of heat from outside.

A more accurate correction based on Barton's method can be applied. Draw a temperature-time graph. The curve obtained will be the reverse of the one obtained in Experiment 34. Through the point representing the initial temperature T_1 , draw a line parallel to the X axis. Through the points representing the minimum temperature T_2 and the temperature T_3 , after it rises by 1 or 2 degrees, draw lines parallel to the Y axis. Let the area of the space between the descending part of the curve and the corresponding co-ordinates be A and that between the ascending part of the curve and the corresponding co-ordinates be B. Then the absorption correction $d T$ is given by

$$d T = \frac{\text{Area A}}{\text{Area B}} \times (T_3 - T_2).$$

Calculations :—

Weight of calorimeter + stirrer	= W_1 grams.
Weight of calorimeter + stirrer + water	= W_2 grams.
Weight of water alone	= $(W_2 - W_1)$ grams.
Weight of calorimeter + stirrer + water + ice	= W_3 grams.
Weight of ice added	= $(W_3 - W_2)$ grams.
Initial temperature of water	= $T_1^\circ \text{C.}$
Final temperature of water	= $T_2^\circ \text{C.}$
Time taken to reach the final minimum temperature	= t_1 seconds.
Rise of temperature during half the time	= $d T.$
$\therefore$ Absorption correction	= $d T^\circ \text{C.}$

∴ Corrected temperature = T₂° - d T.

Heat lost by water and calorimeter } = { (W₂ - W₁) + W₁s } × { T₁ - (T₂ - dT) }

Heat gained by ice for melting and for rising in temperature from 0°C } = (W₃ - W₂) L + (W₃ - W₂) (T₂ - 0)

∴ (W₃ - W₂) L + (W₃ - W₂) × T₂ = { (W₂ - W₁) + W₁s } { T₁ - (T₂ - dT) }

∴ L = { (W₂ - W₁) + W₁s } { T₁ - (T₂ - dT) } - (W₃ - W₂) T₂ / (W₃ - W₂).

Tabulate the results as follows :—

I. Balance Readings :—

Load on Left Pan	Weights on Right Pan	Turning points		Resting point	Accurate weight (correct to a centigram)
		Left	Right		
Empty	Zero				
Calorimeter + stirrer	x grams				
„	x ± 0.01 grams.				W ₁ grams.
Calorimeter + stirrer + water	y grams.				
„	y ± 0.01 grams.				W ₂ grams.
Calorimeter + stirrer + water + ice	z grams.				
„	z ± 0.01 grams.				W ₃ grams.

II. *Time-Temperature readings* :—

Time	Temperature
------	-------------

III. *Absorption correction* :— dT from graph =

Repeat the experiment twice or thrice and find the mean value of the latent heat of ice.

(B) *To determine the specific heat of a liquid using ice*

Determine the latent heat of ice first, as described in the above experiment.

In place of water in the calorimeter, take the liquid. [It is possible that, if a liquid like coconut oil is taken, addition of too much of ice will produce an emulsion and will ultimately freeze the oil. This must be guarded against.] Follow the instructions given in the experiment described above and take all the readings. Let S be the specific heat of the liquid. Use the same symbols for the other quantities.

$$\text{Heat lost} = \text{Heat gained}$$

$$\begin{aligned} \therefore \{ (W_2 - W_1) S + W_1 s \} \times \{ T_1 - (T_2 - dT) \} \\ = (W_3 - W_2) L + (W_3 - W_2) (T_2 - 0) \\ \therefore S = \frac{(W_3 - W_2) L + (W_3 - W_2) T_2 - W_1 s \{ T_1 - (T_2 - dT) \}}{(W_2 - W_1) \{ T_1 - (T_2 - dT) \}} \end{aligned}$$

Substitute the known values for the various symbols and calculate the specific heat of the liquid.

EXPERIMENT 37

LATENT HEAT OF STEAM

Aim :—To determine the latent heat of steam.

Apparatus required :—Apparatus for producing dry steam, calorimeter.

Description of apparatus :—The apparatus for producing dry steam consists of (1) a steam boiler S , (2) a leading tube T wrapped with non-conducting material like cotton or wool and (3) a steam

trap. Part of the steam issuing from the boiler condenses all along the way till it reaches the calorimeter. The condensed water must be prevented from entering the calorimeter along with the steam. The leading tube is wrapped in cotton or wool to reduce condensation. It slopes upwards to enable the condensed water to flow back into the boiler. The steam trap is for collecting the condensed water and letting it out just before steam is passed into the calorimeter. In spite of all the precautions taken, it is likely that due to its high temperature some steam may condense and gain access to the calorimeter. This will affect the value obtained for the latent heat.

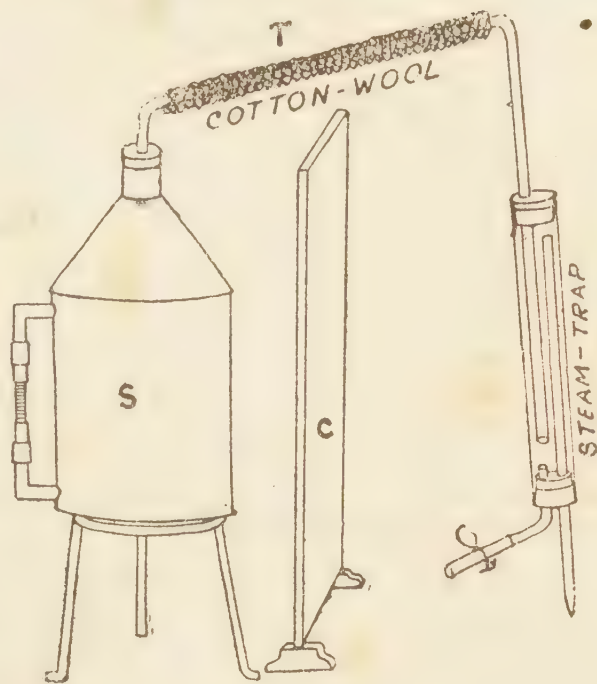


Fig. 66

The calorimeter is of the usual type used for specific heat determinations. It consists of an inner polished calorimeter suspended in an outer calorimeter, out of contact with it. The outer steam trap is surrounded by a wooden box.

(A) Latent heat of steam

Procedure :—Set up the steam boiler on a tripod stand. Connect the leading tube and the steam trap to it. Heat the boiler. Mount a large asbestos screen C between the boiler and the steam trap to prevent heat from the boiler reaching it by radiation.

Find the weight of the empty inner calorimeter and stirrer correct to a centigram. Fill it with water to about two-thirds of its height and again find the weight. The difference gives the weight of water taken. Carefully suspend it inside the outer calorimeter. Place it in the wooden box. Place a sensitive thermometer in the water for noting its temperature.

When steam issues freely from the nozzle of the outlet tube in the steam trap, arrange to pass it into the water in the calorimeter. Note the temperature of the steam issuing from

the nozzle of the steam trap. Let it be T . First stir the water well and note its temperature. Have a stop-clock ready. Let out all the condensed water from the steam trap. Bring the calorimeter under the steam trap and quickly immerse the nozzle of the outlet tube into the water, simultaneously starting a stop-clock. Stir the water well as the steam mixes with the water and raises its temperature. When the rise of temperature is from 5 to 10°C , remove the calorimeter quickly to a distance. Stir the water and note the temperature every $.15$ seconds. Continue it till the temperature reaches the maximum and then falls by 1 or 2°C . [Some skill is required to do the above manipulation and some rehearsal and practice may enable one to acquire it.]

When it is cool, remove the calorimeter and stirrer and find its weight again. The difference between this weight and the previous one gives the weight of steam passed into the water.

Radiation Correction:—A correction has to be applied for cooling due to radiation, while the temperature is rising. The approximate radiation correction is calculated as follows. Find the fall of temperature, after the maximum temperature has been reached, in half the time taken for the temperature to rise from its initial value to the maximum. Or, find half the fall of temperature after the maximum temperature has been reached, in the time taken for the temperature to rise from its initial value to the maximum. Either of the above gives the correction which must be added to the maximum temperature.

A more accurate correction is obtained by Barton's method. With the time-temperature readings, draw a graph. Calculate the correction from the graph by the method indicated in Experiment 34.

Calculations :

$$\begin{array}{ll}
 \text{Weight of calorimeter + stirrer} & = W_1 \text{ grams.} \\
 \left. \begin{array}{l} \text{Weight of calorimeter + stirrer} \\ \text{+ water} \end{array} \right\} & = W_2 \text{ grams.} \\
 \therefore \text{Weight of water alone} & = (W_2 - W_1) \text{ grams.} \\
 \left. \begin{array}{l} \text{Weight of calorimeter + stirrer} \\ \text{+ water + steam} \end{array} \right\} & = W_3 \text{ grams.} \\
 \therefore \text{Weight of steam passed} & = (W_3 - W_2) \text{ grams.} \\
 \text{Initial temperature of water} & = T_1^{\circ}\text{C} \\
 \text{Maximum temperature reached} & = T_2^{\circ}\text{C}
 \end{array}$$

Time taken to reach the maximum temperature } = t_1 secs.

Fall of temperature in $\frac{t_1}{2}$ seconds after the maximum temperature was reached } = $d T$

∴ Radiation correction = $d T$

∴ Corrected final temperature = $T_2 + d T$

Temperature of steam = $T^\circ \text{C}$

Heat lost = Heat gained

$$(W_3 - W_2) L + (W_3 - W_2) (T - T_2) = (W_2 - W_1 + W_1 s) (T_2 + d T - T_1)$$

$$\therefore L = \frac{(W_2 - W_1 + W_1 s) (T_2 + d T - T_1) - (W_3 - W_2) (T - T_2)}{(W_3 - W_2)}$$

Tabulate the readings as follows :—

I. Balance Readings.

Load on Left Pan	Weights on Right Pan	Turning points		Resting point	Weight correct to a centigram
		Left	Right		
Nil	Zero				
Calorimeter + stirrer "	x grams				W_1 grams
	$x \pm 0.01$ grams				
Calorimeter + stirrer + water "	y grams				W_2 grams
	$y \pm 0.01$ grams				
Calorimeter + stirrer + water + steam "	z grams				W_3 grams
	$z \pm 0.01$ grams				

II. *Time-Temperature readings :*

Time	Temperature
------	-------------

III. *Radiation correction :*

Repeat the experiment and find the mean value of the Latent heat of steam.

Note :—In order that the rise of temperature may not be too high, a large volume of water has to be taken. So, to determine the weight of steam condensed accurately, a small, thin-walled copper condenser with inlet and outlet tubes may be used. The condenser is kept under the water, with the inlet and outlet tubes alone above the surface of the water. Steam is let into the condenser. The uncondensed steam escapes. By weighing the condenser before and after passing steam, the weight of condensed steam is determined.

(B) To determine the specific heat of a liquid,
assuming the latent heat of steam

In place of water, take the given liquid in the calorimeter. Pass steam into it and note the rise of temperature. Follow the instructions given above and perform the experiment. If S is the specific heat of the liquid,

$$S = \frac{(W_3 - W_2) L + (W_3 - W_2) (T - T_2) - W_1 s (T_2 + dT - T_1)}{(W_2 - W_1) (T_2 + dT - T_1)}$$

EXPERIMENT 38

MELTING POINT OF A SOLID (COOLING CURVE) AND BOILING POINT OF A LIQUID

Aim :—To determine (1) the melting point of a solid by drawing its cooling curve and (2) the boiling point of a liquid.

(1) Melting Point of a Solid

Apparatus required :—A test tube with a large cross-section or a calorimeter ; a large calorimeter to serve as a constant temperature enclosure ; thermometer ; stop-clock ; solid (paraffin or naphthalene).

Procedure:—Introduce the solid in small bits into the test-tube (or calorimeter) till it occupies about 2 to 3 inches of the test-tube. Place the test-tube in a beaker of water and heat it. The solid begins to melt, as heat reaches it from the hot water. Wait till all the solid has melted. Introduce a thermometer into the molten liquid. Note the temperature.

Keep a stop-clock ready. When the solid has completely melted and risen in temperature (about 10° higher than its melting point), remove it and suspend it inside the constant temperature enclosure. Note the temperature and start the stop-clock. Take the readings of the thermometer every 30 seconds. The temperature will fall for some time. As the liquid commences to solidify, the temperature will cease to fall. It will remain constant till all the liquid has solidified. It will then begin to decrease steadily.

Graph:—The constant temperature represents the melting point of the solid. A graph will indicate it clearly. Represent

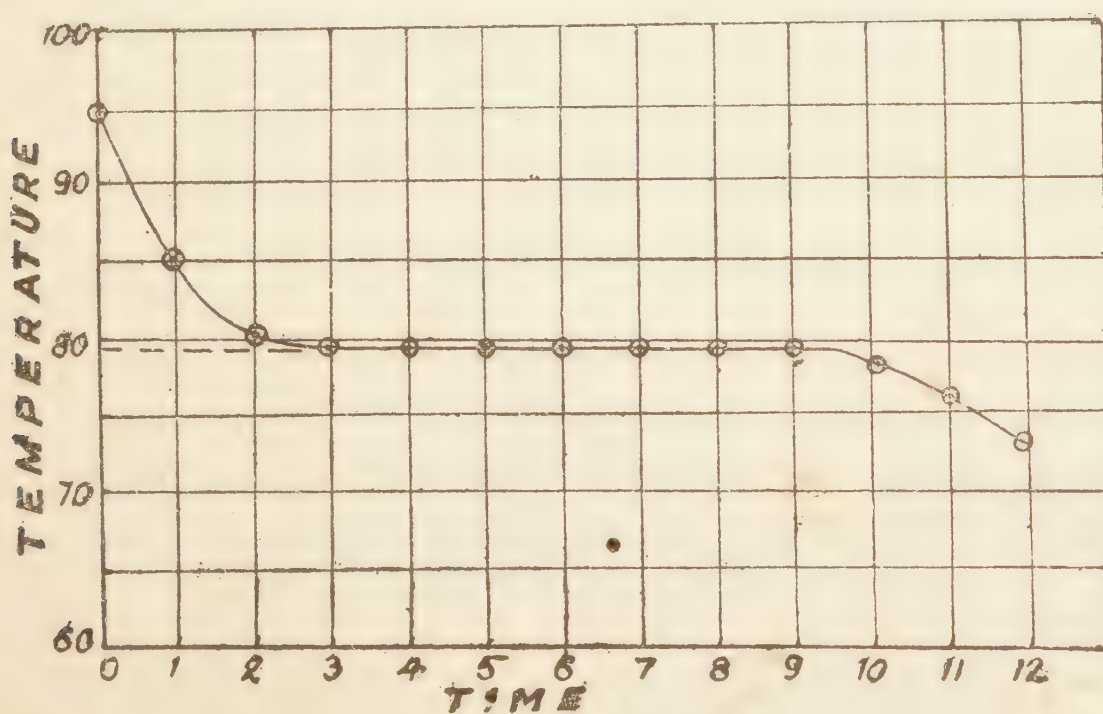


Fig. 67

times along the X axis and the corresponding temperatures along the Y axis. Draw a curve through the points plotted. It will represent the cooling curve of the solid. The cooling curve will have a flat portion, parallel to the X axis, representing a constant temperature. This corresponds to the *melting point* of the solid.

[The flat portion will be clear and sharp, only if the solid is pure and has a crystalline structure. If the solid is a mixture of different substances, the curve will not have a sharp flat portion.]

Latent Heat of the Solid:—Besides being used for finding the melting point of the solid, the cooling curve can be used for determining the latent heat of the solid.

First, find the weight of the test-tube alone. Let it be W_1 . After the solid has been introduced into it, find the weight W_2 . The weight of the solid is $(W_2 - W_1)$. Let the time for which the temperature is constant at the melting point be t seconds. If L is the latent heat, the liquid gives out $\frac{(W_2 - W_1) \times L}{t}$ calories of heat per second during the period. It is this heat that is released during solidification that maintains the temperature constant.

Take an identical test tube. Find its weight. Fill it with water to the *same* height in it as the molten liquid in the other test tube. Find the weight. Keeping it in a water bath, raise its temperature by about 3 or 4° above the melting point of the solid. Take it out, suspend it in the same enclosure and allow it to cool. Note the temperature every 30 seconds, till it falls 3 or 4° below the melting point of the solid. Draw the cooling curve. From the graph, find the time taken for the water to fall in temperature from $(T + \frac{1}{2})^\circ\text{C}$ to $(T - \frac{1}{2})^\circ\text{C}$, where T is the melting point of the solid. Calculate the quantity of heat given out per second by the hot water at temperature $T^\circ\text{C}$. If W is the weight of water taken + water equivalent and x is the time required for the fall of temperature of 1°C , the quantity of heat given out per second is $\frac{W}{x}$ calories.

$$\therefore \frac{(W_2 - W_1) \times L}{t} = \frac{W}{x} = Q \text{ (say)}$$

$$\therefore L = \frac{Q \times t}{(W_2 - W_1)} \text{ calories per gram}$$

(2) Boiling Point of a Liquid

Procedure:—Prepare a J tube, with the end of the shorter limb in it closed. Pour dry mercury into it, till it occupies the whole of the shorter limb and a small part of the longer limb,

Introduce carefully a few drops of the liquid through the mercury into the shorter limb. Let it float to the top of the mercury in it.

[It is essential that no air gets in along with the liquid. If it does, the result will be inaccurate].

Place the J tube in a water bath (whose maximum temperature is at least 10° degrees above the boiling point of the liquid) with the shorter limb completely immersed in water. The longer limb with the open end must be above the level of the water. Heat the water bath slowly. As the temperature rises, the liquid vapourises and pushes down the mercury. Note carefully the temperature at which the levels of mercury on both sides are the same. Raise the temperature of the bath a little above this. Cease heating and allow it to cool. Note the temperature when the two levels are the same. Repeat three or four times and note the mean temperature. This gives the *boiling point* of the liquid.

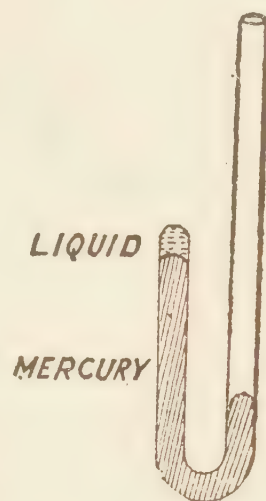


Fig. 68

When the two levels are the same, the saturation vapour pressure of the liquid is equal to the atmospheric pressure. The boiling point of a liquid is the temperature at which its saturation vapour pressure is equal to the atmospheric pressure. Hence, the temperature at which the two levels are the same is the boiling point of the liquid.

EXPERIMENT 39

NEWTON'S LAW OF COOLING—SPECIFIC HEAT OF A LIQUID

Aim .—(1) To verify Newton's Law of cooling and (2) to determine the specific heat of a liquid by the method of cooling.

(A) Newton's Law of Cooling

Apparatus required :—A spherical calorimeter with an outer surface which is polished or uniformly blackened, outer calorimeter, thermometer, stop-clock.

The spherical calorimeter used for this experiment has a diameter of 5 or 6 cms. It has a short neck with a small hole at

the bottom of the neck, on one side of it. When the level of the liquid is a little above the hole, the excess flows out of the hole. So, the volume of liquid in it is always constant.

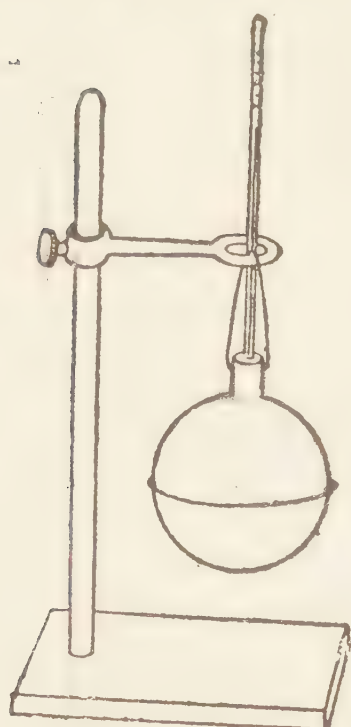


Fig. 69

Procedure:—Find the weight of the calorimeter. Fill it with hot water at a temperature of about 85°C . The liquid will stand up to the hole in the neck. Suspend it carefully inside the outer calorimeter. Insert the thermometer in the water. Note the temperature and simultaneously start a stop-clock. Note the temperature every half minute, till the temperature falls to about 40°C . Take out the calorimeter and find its weight.

Graph:—Taking time along the X axis and temperature along the Y axis, plot the points. Draw a smooth curve. It represents the time-temperature cooling curve of the liquid.

Newton's Law of Cooling:—Newton's Law of Cooling states that the rate of cooling of a hot body depends on the excess of its temperature over that of the surroundings, the nature and area of the surface remaining the same.

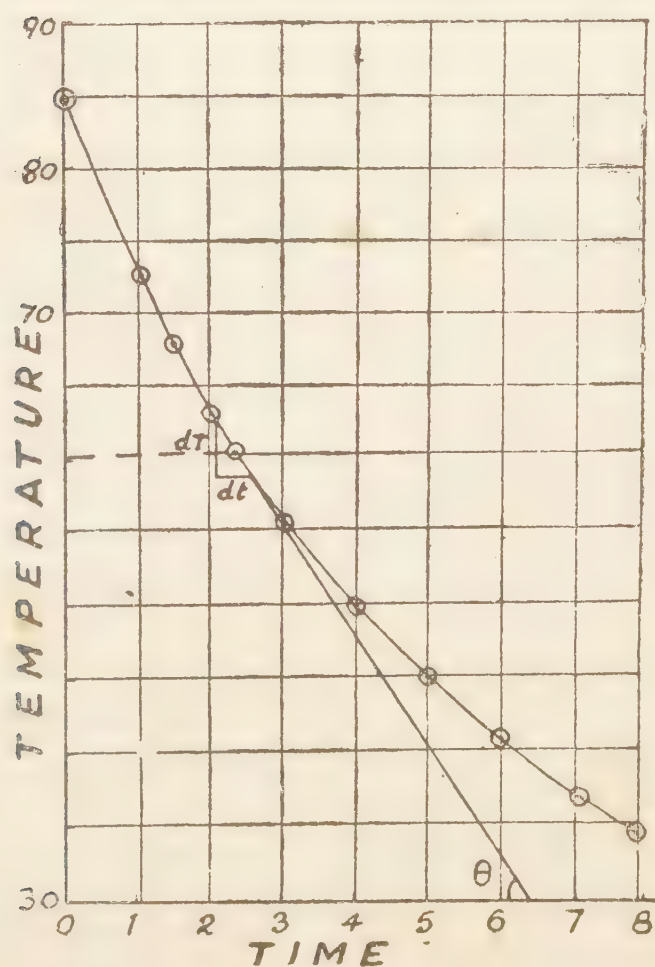


Fig. 70

The rates of fall of temperature at various temperatures can be found from the graph drawn. The slope of the curve at any point gives the rate of fall of temperature at the temperature. Take any point on the cooling curve corresponding to a temperature of, say, 60°C . Draw a tangent to the curve at the point. Produce it to meet the X axis. Measure the angle θ , between the tangent and the X axis. Calculate the tangent of this angle, taking the scales adopted on the X and Y axes into due consideration. It gives the rate of fall of temperature at this temperature.

Alternatively, find from the graph the time taken for the temperature to fall from 60.5°C to 59.5°C . The difference in

temperature divided by the time of fall is equal to the rate of fall of temperature at 60° C.

Find the rates of fall of temperature at 75°, 70°, 65°, 60°, 55° etc. The rate of fall of temperature at each temperature divided by the difference in temperature between that of the liquid and the surroundings will be a constant.

Tabulate the results as follows :—

Tempe- rature of surround- ings	Tempe- rature of liquid	Rate of fall of temperature	Rate of fall of temperature Excess of temperature
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The values in the last column will be constant. Since the rate of cooling is proportional to the rate of fall of temperature, the law is verified.

Emissivity of the surface :—The emissivity of a surface at any temperature is the quantity of heat given out per second by 1 sq. cm. of the radiating surface, when the difference in temperature between the surface and the surroundings is 1° C.

Find the mean diameter of the spherical calorimeter with a vernier calipers. Calculate the area of the surface. Let it be A. Let the rate of fall of temperature at temperature T_1 , as ascertained from the graph, be dT per second. Let the temperature of the surroundings be T . Then, the emissivity e of the surface at temperature T_1 is given by

$$e = \frac{\{(W_2 - W_1) + W_1 s\} dT}{A \times (T_1 - T)}$$

where W_1 is the weight of the calorimeter,

W_2 is the weight of the calorimeter + water

and s is the specific heat of the material of the calorimeter.

Calculate the emissivity of the surface of the calorimeter at various temperatures.

(B) Specific Heat of a Liquid by Method of Cooling

Apparatus required :—Two identical spherical calorimeters, with polished or blackened surfaces, liquid, thermometer.

Procedure :—If two identical calorimeters are available, it is well and good. Otherwise, if only one calorimeter is available,

perform the cooling experiment, first with water in it and then with the liquid in it.

Find the weight of the calorimeter empty. Fill it with hot water at about 85°C . The excess of water will flow out through the hole in the neck. Suspend it carefully inside the outer calorimeter. Insert a thermometer into the water. Note the temperature and simultaneously start a stop-clock. Note the temperature every half minute till the temperature falls to 50°C . Take out the calorimeter and, when it is cold, find its weight.

Throw out the water and dry the calorimeter. Fill it with the given hot liquid, heated separately in a beaker to about 85°C . The excess of liquid will flow out through the hole in the neck. Suspend it carefully inside the outer calorimeter. Insert a thermometer into it. Start a stop-clock and note the temperature of the liquid every half minute till it falls to 50°C . Take out the calorimeter and find its weight after it has cooled.

Graph:—Taking time along the X axis and temperature along the Y axis, plot the points for water and the liquid. Draw

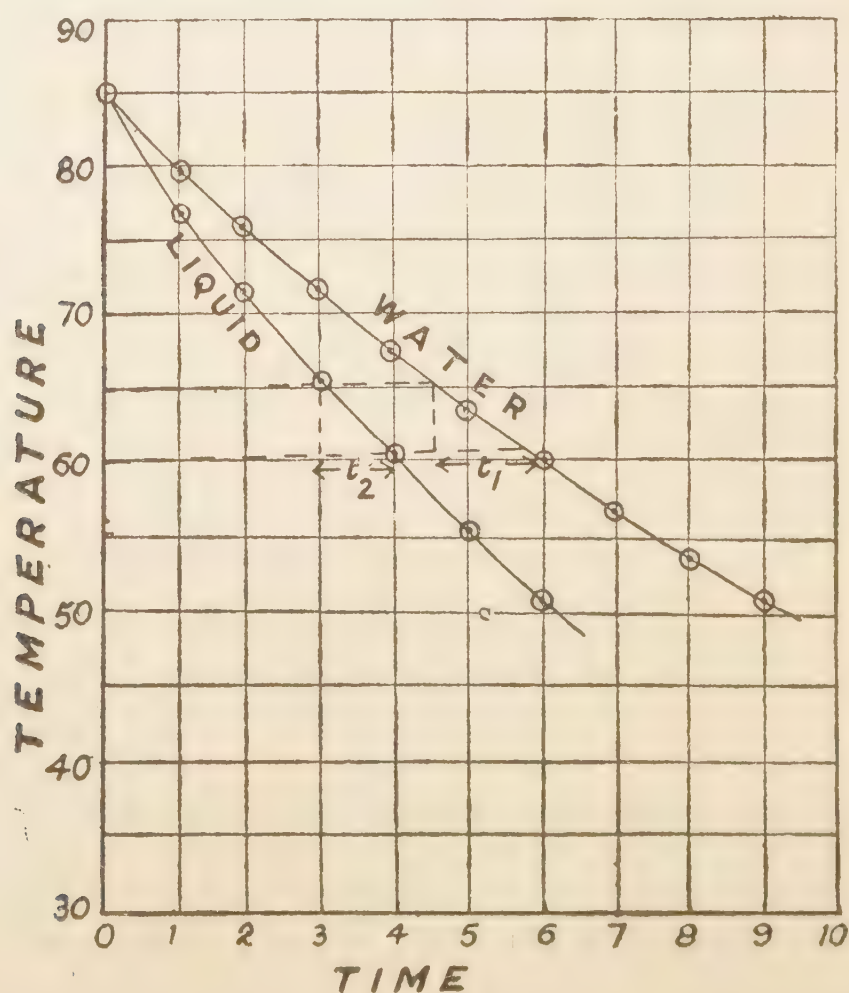


Fig. 71

smooth curves through the points. They will represent the cooling curves of water and the liquid for the specified range of temperature.

Find out from the cooling curves, the times taken for water and the liquid to cool from 80° to 75°C , 75° to 70°C , 70° to 65°C , 65° to 60°C , etc.

Calculations :—

Weight of empty calorimeter = W_1 grams.

Weight of calorimeter + water = W_2 grams.

Weight of calorimeter + liquid = W_3 grams.

Specific heat of the liquid = S

Specific heat of the material of the calorimeter } = s

Time taken for water to cool from 75° to 70°C } = t_1 seconds.

Time taken for the liquid to cool through the same range 75° to 70°C } = t_2 seconds.

According to Newton's law of cooling, the rates of cooling for water and for the liquid for the range 75° to 70° must be the same, as the other factors, such as the nature and area of the radiating surface are the same. So,

$$\frac{\{(W_2 - W_1) + W_1 s\} (75 - 70)}{t_1} = \frac{\{(W_3 - W_1)S + W_1 s\} (75 - 70)}{t_2}$$

$$\therefore (W_3 - W_1) S + W_1 s = \{(W_3 - W_1) + W_1 s\} \frac{t_2}{t_1}$$

$$\therefore S = \frac{\{(W_2 - W_1) + W_1 s\} \frac{t_2}{t_1} - W_1 s}{(W_3 - W_1)}$$

Calculate the values of the specific heat for the various ranges.

Note :—It is absolutely essential that the volumes of water and the liquid taken must be *exactly the same*. Then only, the radiating surfaces will be equal in area and the conditions under which cooling takes place will be identical. So, if a spherical calorimeter of the type described is not available, take particular care to see that equal volumes of hot water and hot liquid are taken.

Tabulate the readings as follows:—

I. *Time - Temperature readings.*

Time in minutes	Temperature		Time in minutes	Temperature	
	Water	Oil		Water	Oil
0	71.8°C	71.8°C	16	61.3°C	53.9°C
1	71.0	70.4	17	60.8	53.2°C
2	70.2	69.0	18	60.2	
3	69.5	67.4	19	59.7	
4	68.8	66.2	20	59.3	
5	68.0	64.3	21	58.7	
6	67.3	63.6	22	58.2	
7	66.6	62.5	23	57.7	
8	66.0	61.4	24	57.3	
9	65.4	60.4	25	56.8	
10	64.7	59.3	26	56.4	
11	64.1	58.4	27	55.9	
12	63.5	57.4	28	55.5	
13	63.0	56.5	29	55.1	
14	62.4	55.6	30	54.6	
15	61.8	54.8	31	54.2	

II. Weight of calorimeter = 21.73 grams.
Weight of calorimeter + water = 76.29 „
∴ Weight of water = 54.56 „
Weight of calorimeter + oil = 70.43 „
∴ Weight of oil = 48.70 „

III. *Rates of fall of Temperature from graph.*

Range	Time of fall of temperature		Time of fall for oil Time of fall for water
	Water	Oil	
70° to 65°	7.3 min.	3.8 min.	0.52
65° to 60°	8.8 „	4.5 „	0.51
60° to 55°	10.5 „	5.2 „	0.50
		Mean	0.51

∴ Specific Heat of oil } = $\frac{(54.56 + 2.17) 0.51 - 2.17}{48.70}$
= 0.55

∴ The Specific heat of the oil by the method of cooling = 0.55.

EXPERIMENT 40

THERMAL CONDUCTIVITY OF COPPER
(SEARLE'S APPARATUS)

Aim :—To determine the coefficient of Thermal Conductivity of copper using Searle's apparatus.

Apparatus required :—Searle's Thermal conductivity apparatus, constant pressure-head reservoir, Stop-clock.

Description of apparatus :—The Searle's apparatus for the determination of the coefficient of thermal conductivity of copper

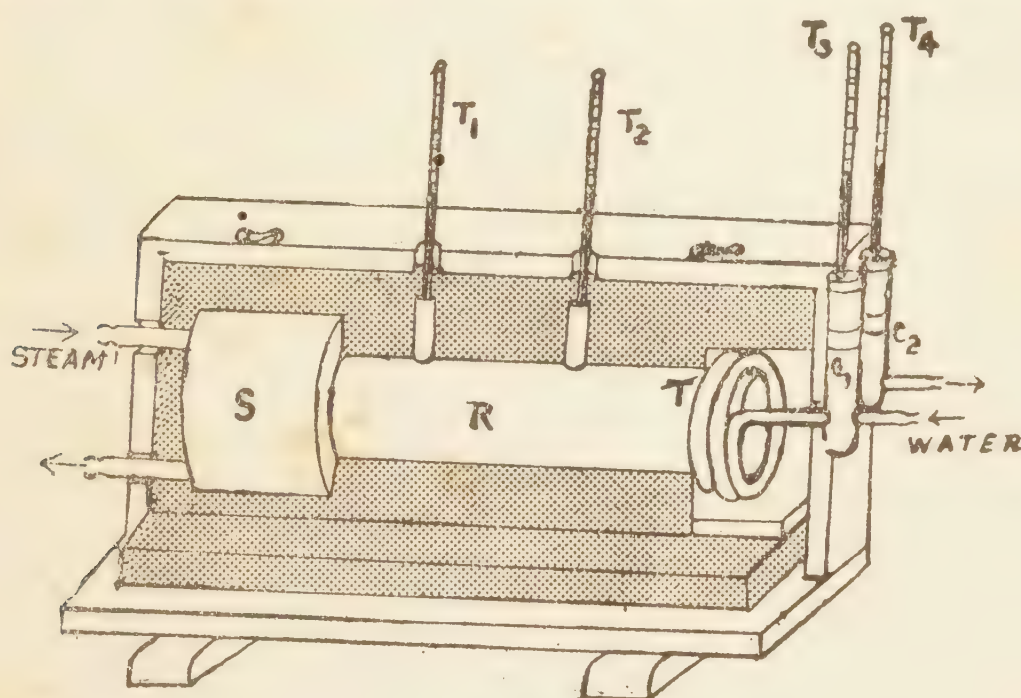


Fig. 72

consists of a solid cylindrical copper rod R about 20 cms. in length and 4 cms. diameter. One end of it projects into a hollow cylindrical steam chamber S about 6 to 7 cms. in diameter and co-axial with the rod. The steam chamber has an inlet for steam and an outlet. Over the other end of the rod is wound a copper tube T in the form of a spiral. The two ends of the copper spiral are led into two cylindrical cups C_1, C_2 . The cups are closed with one-holed rubber stoppers through which thermometers can be introduced. The cups have small tubes inserted into them at the bottom. One of them serves as an inlet for water, which circulates through the spiral and issues out through the other tube. The inlet tube is connected to a constant pressure-head reservoir (Fig. 73) which provides a current of water circulating with a constant speed. On the copper rod, two holes are drilled perpendicular to its length at a

distance of 10 cms. from each other. Small brass tubes are fixed in these holes. A little mercury is poured into each of them. They serve as receptacles for thermometers. The mercury ensures good contact between the bulb and the copper rod.

The rod with the steam chamber at one end and the spiral at the other end is enclosed in a rectangular wooden box. The interspace between the rod and the box is filled with compressed wool which prevents loss of heat by conduction or convection. The two cups attached to the ends of the spiral are outside the box.

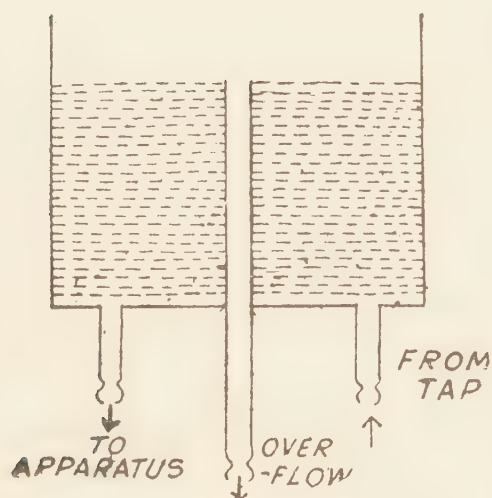


Fig. 73

Procedure :—Connect the tube in one of the cups attached to the spiral to the constant pressure-head reservoir, by a long rubber tube. Connect a short rubber tube to the tube in the other cup.

Insert two thermometers T_3 , T_4 , one in each of the cups. They will indicate the temperatures of the incoming and outgoing water, after circulating through the spiral.

Insert two thermometers T_1 , T_2 , one in each of the holes on the rod. They will indicate the temperatures of the rod at the respective points.

Connect the inlet tube fixed to the steam chamber to a steam boiler by a long rubber tube. Connect a short rubber tube to the outlet tube to lead the steam away.

Heat the boiler and allow steam to pass through the steam chamber. The end of the rod projecting into the chamber is heated by the steam. The heat is conducted along the rod. The thermometers T_1 , T_2 placed in the tubes on the sides of the rod rise in temperature. Circulate water through the spiral at the other end of the rod. The thermometers there T_3 , T_4 will indicate the temperatures of the incoming and outgoing water.

When all the four thermometers show constant temperatures, there is thermal equilibrium over every cross-section of the rod. Note the temperatures. Place a weighed beaker under the outlet tube in the cup fixed to the end of the spiral, collect the water for

a few minutes, noting the time with a stop-clock. Find the weight of water collected. From that, the rate of flow of water can be calculated.

Alter the rate of flow of water by altering the pressure-head. The temperatures indicated by the thermometers will change. Wait till they become steady. Then, find the rate of flow of water, by collecting the water issuing in a definite interval of time, measured by a stop-clock and finding its weight.

Take three or four sets of readings in this manner. Cut off the supply of steam. When the rod is cool, measure the length between the centres of the tubes fixed on the side of the rod. Measure the mean diameter of the rod with a vernier calipers.

Calculations :—Let T_1 and T_2 be the temperatures noted on the thermometers placed in the tubes fixed on the side of the rod ; let l be the distance between the centres of the tubes ; let A be the area of cross-section of the rod and let K be the coefficient of thermal conductivity. Then, the quantity of heat Q conducted across any cross-section of the rod per second is given by,

$$Q = \frac{K \times A \times (T_1 - T_2)}{l}.$$

Let T_3 and T_4 be the temperatures of the incoming and outgoing water circulating through the spiral and let W be the weight of water collected in t seconds. The quantity of heat Q absorbed by the water per second is given by,

$$Q = \frac{W}{t} \times (T_4 - T_3)$$

$$\therefore \frac{K \times A \times (T_1 - T_2)}{l} = \frac{W \times (T_4 - T_3)}{t}$$

$$\therefore K = \frac{W \times l \times (T_4 - T_3)}{A \times t \times (T_1 - T_2)}.$$

Calculate the coefficient of thermal conductivity from each set of values.

Tabulate the results as follows :—

I. *Readings of the thermometers when the temperatures are steady:*

T_1	T_2	$T_1 - T_2$	T_3	T_4	$T_4 - T_3$
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II. Rate of flow of water :

Weight of beaker (grams)	Weight of beaker + water (grams)	Weight of water alone (grams)	Time of flow in seconds	Rate of flow of water
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III. Distance l between holes on rod = cms.

Mean diameter d of the rod measured with vernier calipers } = cms.

$\therefore$ Mean area A of rod = sq. cms.

From the data, calculate K .

EXPERIMENT 41

THERMAL CONDUCTIVITY OF A BAD CONDUCTOR (LEE'S DISC METHOD)

Aim :—To determine the coefficient of thermal conductivity of a bad conductor (card-board) using Lee's disc.

Apparatus required :—Lee's disc, steam-boiler, card-board.

Description of apparatus :—The Lee's disc consists of (1) a heavy circular metallic disc D about 10 cms. in diameter and 1 cm. thick suspended by three strong strings from a ring R and (2) a hollow cylindrical steam chamber S , 10 cms. in diameter and 5 cms. high, which rests on the disc. The disc has a hole in it for introducing a thermometer T_2 . The steam chamber has an inlet and an outlet for letting in and letting out steam. There is another hole in it for introducing a thermometer T_1 . The disc and the steam chamber are nickel-or chromium-plated and so, have brightly polished surfaces.

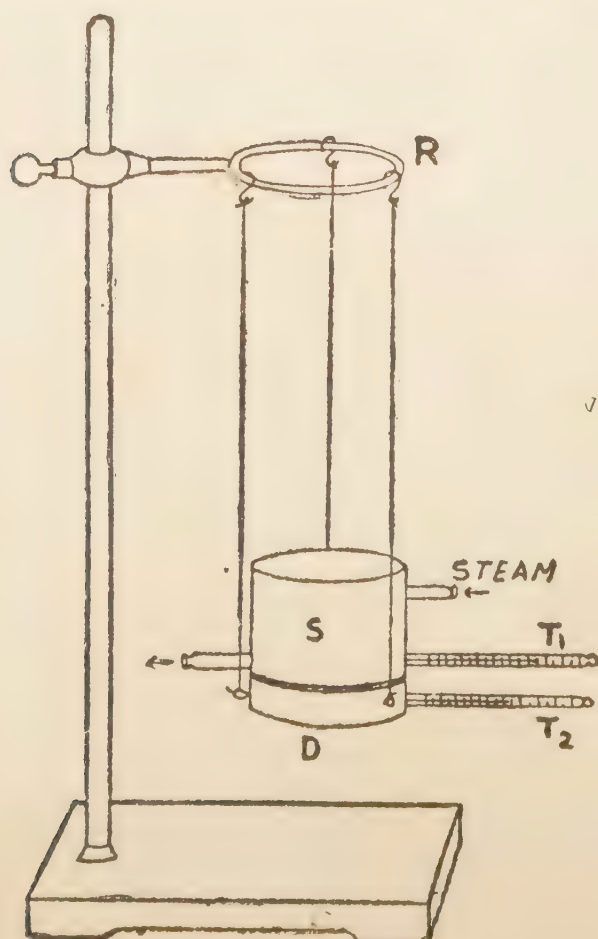


Fig. 74

Procedure :—The metallic disc is hung horizontally from the ring. The card-board, cut to the

size of the disc is placed on it. The steam chamber is placed over the card-board, so that the latter is sand-witched between the disc and the chamber. The two thermometers are placed in position, one in the disc and the other in the chamber.

The steam boiler is set up and connected to the steam chamber by a long rubber tube. Steam is passed into the chamber. A long rubber tube connected to the outlet tube leads the escaping steam away from the disc.

The thermometers indicate rise in temperature. T_1 gives the temperature of the chamber. T_2 gives the temperature of the disc. The disc rises in temperature due to the heat conducted across the card-board. When the two temperatures are steady for a fairly long time, say, from 15 to 25 minutes, note them and cut off the steam supply.

Gently remove the card-board between the disc and the chamber. Place the chamber directly in contact with the disc. Again pass steam into the chamber. The disc gets heated more rapidly now. When its temperature is about 7 or 8°C above the temperature T_2 , reached by it formerly, cut off the steam and carefully remove the steam chamber.

Allow the disc to cool. When its temperature falls exactly to 5° above T_2 (its former temperature), start a stop-clock. Note the temperature every half minute till it falls to 5° below T_2 , its former temperature.

Measure the mean thickness and diameter of the disc with a vernier calipers. Find its weight. Measure the mean thickness of the card-board with a screw gauge. Take readings at not less than six different places on it.

Calculations :

Temperature of steam chamber	=	$T_1 ^\circ \text{C}$
Steady Temperature of disc	=	$T_2 ^\circ \text{C}$
Mean thickness of card-board	=	$l \text{ cms.}$
Mean thickness of disc	=	$h \text{ ,,}$
Mean diameter of disc	=	$d \text{ ,,}$
Weight of disc	=	$W \text{ grams.}$
Time taken for the disc to cool from $(T_2 + \frac{1}{2}) ^\circ \text{C}$ to $(T_2 - \frac{1}{2}) ^\circ \text{C}$	}	$t \text{ seconds}$
Specific Heat of the material of the disc		
	=	S

Now, the quantity of heat Q conducted across the card-board, when the temperatures are steady, is given by,

$$Q = \frac{K \times A \times (T_1 - T_2)}{l} \text{ calories}$$

This is lost by radiation from the exposed portions of the disc.

The quantity of heat lost per second by each sq. cm. of the area of the disc when it cools from $(T_2 + \frac{1}{2})^\circ \text{C}$ to $(T_2 - \frac{1}{2})^\circ \text{C}$ is equal to

$$\frac{W \times S \times \left\{ (T_2 + \frac{1}{2}) - (T_2 - \frac{1}{2}) \right\}}{t \times (2\pi r^2 + 2\pi rh)} = \frac{W \times S}{t \times (2\pi r^2 + 2\pi rh)}$$

$\therefore$ The quantity of heat, lost per second by the exposed portions of the disc is

$$\begin{aligned} & \frac{W \times S}{t \times (2\pi r^2 + 2\pi rh)} \times (\pi r^2 + 2\pi rh) \\ &= \frac{W \times S (r + 2h)}{2(r + h) \times t} \text{ calories.} \\ \therefore \frac{K \times A \times (T_1 - T_2)}{l} &= \frac{W \times S (r + 2h)}{2(r + h) \times t} \\ \therefore K &= \frac{W \times S \times l \times (r + 2h)}{2 \times A \times (T_1 - T_2) \times (r + h) \times t} \end{aligned}$$

The time required for the disc to cool from $(T_2 + \frac{1}{2})^\circ \text{C}$ to $(T_2 - \frac{1}{2})^\circ \text{C}$ is best taken from a time-temperature graph plotted with the readings taken.

Tabulate the readings as follows :—

I. *Readings of the Thermometers when the temperatures are steady.*

T_1	T_2	$T_1 - T_2$
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II. *Time-Temperature readings when the lower disc is cooled.*

Time	Temperature	Time	Temperature
------	-------------	------	-------------

Time (t) taken for the lower disc to cool from $(T_2 + \frac{1}{2})^\circ \text{C}$ to $(T_2 - \frac{1}{2})^\circ \text{C}$, read from the graph = secs.

III. *Thickness of cardboard* :—Measured by a screw gauge ;
Mean thickness (at least six readings) $l =$ cms.

IV. *Diameter and thickness of lower disc* :—Using vernier calipers ;

Mean diameter of the lower disc = cms.

∴ Mean radius of the lower disc (r) = cms.

Mean thickness of the lower disc. (h) = cms.

(at least six readings to be taken in each case).

Weight of lower disc (W) = grams.

With these data calculate K, from the formula.

EXPERIMENT 42

MECHANICAL EQUIVALENT OF HEAT

Aim :—To determine the Mechanical Equivalent of Heat using Searle's Friction cone apparatus.

Apparatus required :—Friction cone apparatus.

Description of apparatus :—The friction cone apparatus designed by Searle consists of two well fitting, brightly polished conical cups of brass. The outer cup rests on two pins fixed to the bottom of a cast iron cup, which serves also as an enclosure.

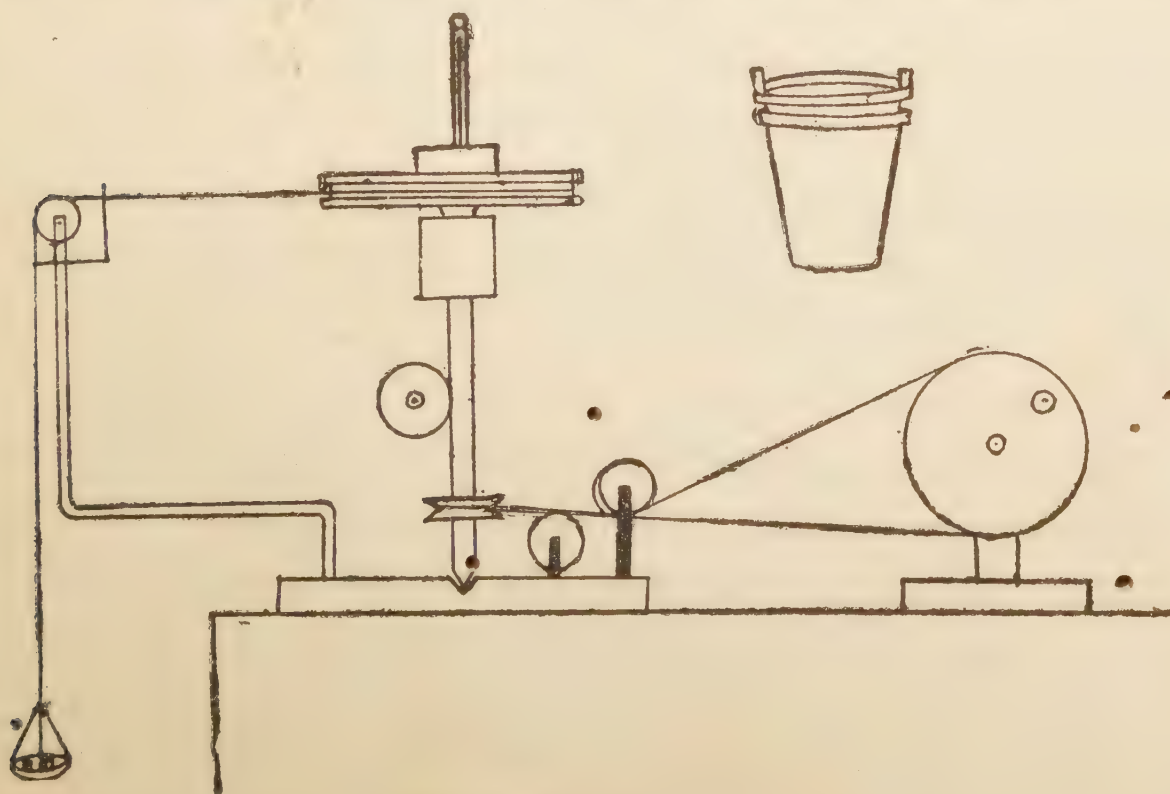


Fig. 75

The cast iron cup is mounted on a vertical spindle which can be rotated about a vertical axis by a belt passing over a pulley in the spindle and a hand wheel. When the spindle rotates, the cast iron

cup and the brass cup inside it rotate along with it. The revolutions of the spindle are automatically registered on a counter attached to it, by a toothed wheel arrangement.

The inner cup has on its top rim, two pins on which rests a circular wooden disc with a groove all round its circumference. A string is tied to a hook fixed in the groove, passed round the groove and then over a small pulley. At the other end, it carries a scale pan with weights. A heavy iron ring placed centrally on the disc makes it sit tightly on the cup. It is also provided with a stirrer.

When weights are placed on the scale pan, it will descend and the wooden disc will rotate. Consequently, the inner cup will rotate. If, however, the outer cup is rotated in the opposite direction, by rotating the spindle at a suitable speed, the inner cup will remain stationary. Then, due to the friction between the cones, work will be done and this will get converted into heat.

Procedure:—Remove the two cups and stirrer and weigh them empty. Fill the inner cup with water to about two-thirds of its height and weigh again. Place the cups in position in the cast iron cup. Introduce a drop of oil between the cups. Place the disc on the inner cup. Pass the string round the groove and over the pulley. Keep some weights in the scale pan.

[If a preliminary experiment is performed for determining the weights to be placed in the scale pan and the suitable speed of rotation, it will save trouble later.]

Note the initial reading of the counter. Introduce the thermometer into the water and note its initial temperature. Start rotating the spindle, simultaneously starting a stop-clock. Rotate the spindle and the outer cup at such a speed, that the inner cup remains stationary, and the scale pan with the weights in it remains in mid-air without rising or falling. If the speed of rotation is too much, the scale pan will rise and if it is too low, it will fall. Stir the water well and note the temperature every half minute. When the rise of temperature is about 5°C , stop the rotation. Continue to note the temperature every half minute till it falls by about 1 or 2°C . From the readings, find the half-

time correction. Note the number of revolutions from the counter. The difference between the final reading of the counter and the initial reading will give the number of revolutions.

Measure the circumference of the disc. Find out the weight of the scale pan and the weights placed in it.

Calculations :—If the outer cup were stationary, the inner cup will be rotated by the weights in the scale pan descending due to gravitational action. The weights will descend by a distance equal to $2\pi r$ for each rotation, where r is the radius of the disc. The work done will be $2\pi r \times Mg$, where Mg is the weight of the scale pan and the weights placed in it. To keep the inner cup and scale pan stationary, the same amount of work has to be done against the friction between the two cups, by rotating the outer cup. So, the total amount of work done against friction is $2\pi r \times Mg \times n$ ergs, where n is the number of revolutions.

The quantity of heat produced is calculated from the rise of temperature. Let W_1 be the weight of the empty cones and stirrer ; let W_2 be the weight of the cones, stirrer and water ; let T_1 be the initial temperature and T_2 be the final temperature ; let dT be the radiation correction; let S be the specific heat of the conical cups. Then, the quantity of heat produced is equal to

$$\{W_1 S + (W_2 - W_1)\} \times \{(T_2 + dT) - T_1\}.$$

$$\therefore J \left. \begin{array}{l} \text{the mechanical} \\ \text{equivalent} \\ \text{of heat,} \end{array} \right\} = \frac{2\pi r n Mg}{\{W_1 S + (W_2 - W_1)\} \times \{T_2 + dT - T_1\}} \text{ ergs per calorie.}$$

Enter the observations thus:—

Weight of empty cups and stirrer = W_1 grams.

Weight of empty cups, stirrer and water = W_2 grams.

Initial temperature of water = $T_1^\circ \text{C}$,

Final temperature of water = $T_2^\circ \text{C}$.

Time taken for the rise of temperature = t_1 secs.

Fall of temperature in $\frac{t_1}{2}$ secs. after the maximum temperature was reached. $\left. \begin{array}{l} \text{the} \\ \end{array} \right\} = dT$

$$\begin{aligned}
 \therefore \text{Radiation correction} &= dT^{\circ}\text{C.} \\
 \therefore \text{Corrected final temperature} &= (T_2 + dT)^{\circ}\text{C} \\
 \text{Weight of scale pan along with the weights in it} &= Mg \\
 \text{Number of revolutions registered by counter} &= n. \\
 \text{Circumference of disc} &= L \text{ or } (2\pi r) \\
 \therefore J &= \frac{2\pi r \times n \times Mg}{(W_1 S + W_2 - W_1)(T_2 + dT - T_1)}
 \end{aligned}$$

SECTION IV

SOUND

EXPERIMENT 43

RESONANCE

Aim :—To determine (1) the velocity of sound in air and (2) the frequency of a tuning fork, by the method of resonance.

Apparatus required :—Resonance apparatus, tuning forks, striking hammer.

Description of apparatus :—The resonance apparatus consists of a long, cylindrical glass tube about one metre in length, mounted on a vertical board. The tube is open at the top. At the bottom, it has an outlet to which a long rubber tube is connected. The other end of the rubber tube is attached to the bottom of a vessel which is filled with water. This vessel can be raised or lowered, thus enabling you to regulate the flow of water into or from the tube. A pinch-cock is attached to the rubber tube. By manipulating this, the flow of water can be regulated.

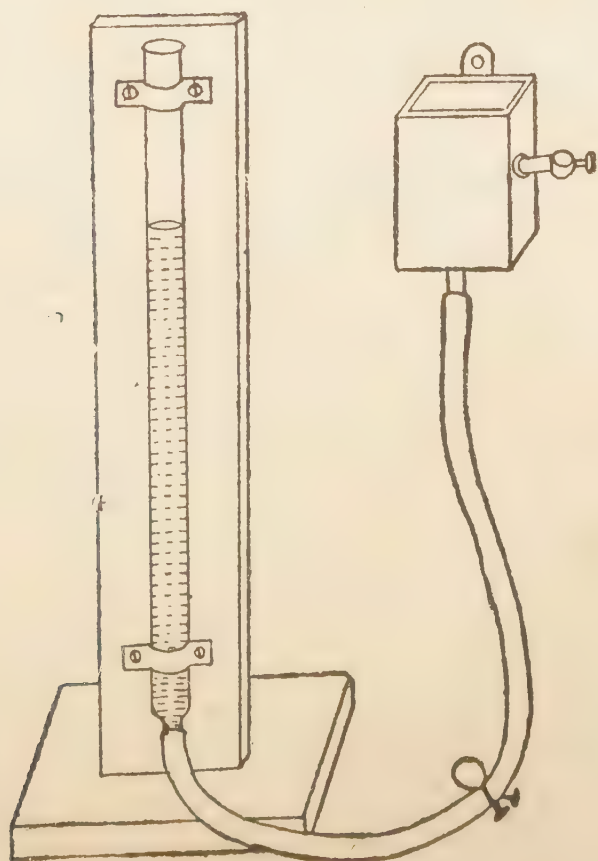


Fig. 76

Note :—If such an apparatus is not available, the experiment can be performed, using cylindrical glass tubes of different lengths and a jar of water. A glass tube is introduced into the water in the

jar. By raising or lowering it, you get a column of air of any desired length above the level of water.

Procedure :—Raise the reservoir so that the level of water rises in the tube. When the level is almost at the top of the tube, strike a tuning fork and hold the vibrating prong near the mouth of the tube horizontally. Gradually lower the reservoir so that the level of water in the tube falls slowly. When the length of the air column approaches a certain value, the note emitted by the tuning fork is augmented by an identical note given out by the air column. The latter note is due to the *forced* vibrations set up in the air column, due to resonance. It increases in loudness and reaches the maximum value for a particular, definite length of the air column. If the length of the air column increases further, the sound decreases in intensity and falls off. Find, by trial, the length of the air column which produces the maximum, sharp sound. Fix the reservoir at that height and measure the length of the air column from the water surface to the mouth of the tube, with a metre scale. Disturb the arrangement and take another reading. Repeat two or three times and take the average. Take another tuning fork of a different frequency and find similarly the shortest length of the air column for which resonance is produced by the tuning fork. Repeat, for three or four tuning forks of different frequencies. Find the shortest length of the resonating air column corresponding to each tuning fork.

Take the first tuning fork again. Lower the reservoir slowly, and find the next length of the air column for which there is resonance. As before, locate the length of the air column for which the resonance is maximum. This length will be roughly three times the first length. Measure the length from the surface of the water to the mouth of the tube. Disturb the position of the reservoir and readjust till you get the resonating column of air. Take the mean of two or three readings. Repeat for the other tuning forks.

• **Calculations :—**The resonance in the air column is due to the stationary vibrations set up in it by the tuning fork. At the surface of the water there is a *node* and at the mouth of the tube there is an *antinode*. The distance between two consecutive nodes or antinodes is half a wave-length ; and the distance between a node and the contiguous anti-node is one-fourth of a wave length.

So, if l_1 is the minimum length of the air column producing resonance, and λ the wave-length of sound,

$$l_1 = \frac{\lambda}{4} - C. \quad (i)$$

In the equation, C is a constant, known as the end-correction.

The antinode is generally situated a little beyond the mouth of the tube. The end-correction depends on the diameter of the tube. It can be taken to be equal to $0.3d$ where d is the diameter of the tube.

$$\therefore \lambda = 4(l_1 + C).$$

Thus, the wave-length of the particular note can be calculated.

The end-correction can, however, be eliminated, if the next length of the resonating air column is measured for the same note. When resonance occurs next, due to the stationary vibrations produced, in between the node on the surface of the water and the anti-node at the mouth of the tube, there will be one more node and one more anti-node in the air column. The length will now be about three-fourths of a wave-length. If it is l_2 ,

$$l_2 = \frac{3\lambda}{4} - C \quad (ii)$$

where C is the end-correction. Subtracting (i) from (ii)

$$l_2 - l_1 = \frac{\lambda}{2}$$

$$\therefore \lambda = 2(l_2 - l_1)$$

Thus, without assuming the end-correction, the wave-length can be calculated. The next length l_3 of the air column producing resonance satisfies the condition,

$$l_3 = \frac{5\lambda}{4} - C. \quad (iii)$$

$$\therefore l_3 - l_2 = \frac{\lambda}{2}$$

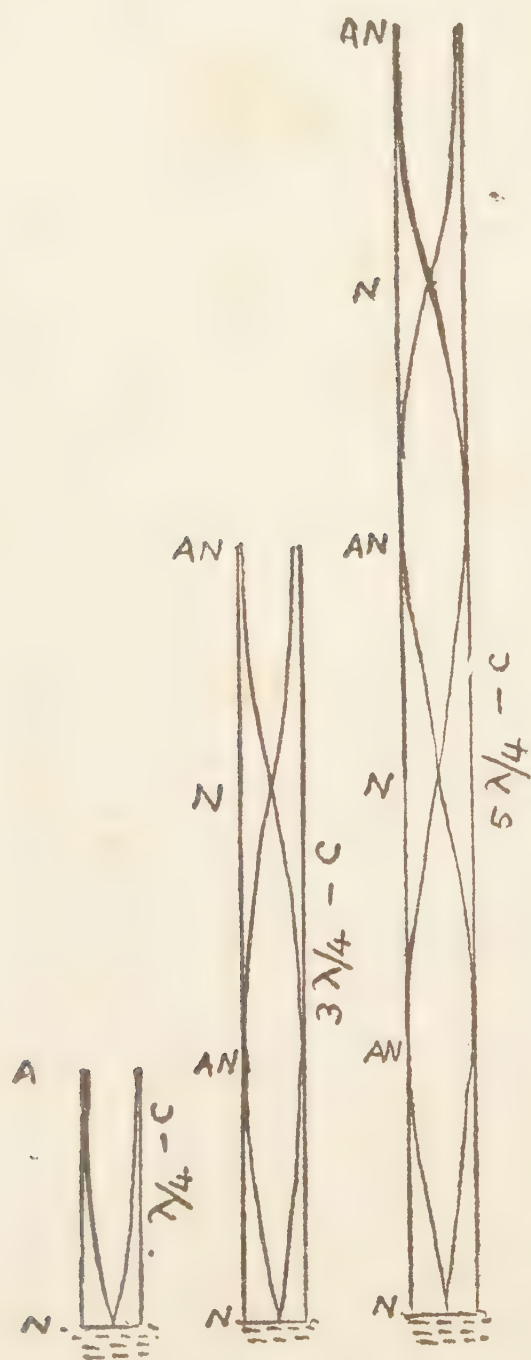


Fig. 77

Again, multiplying (i) by 3 and subtracting from (ii), you get,

$$(l_2 - 3l_1) = 2C.$$

$$\therefore C = \frac{l_2 - 3l_1}{2}$$

Thus the end-correction is calculated.

Velocity of sound in air :—The velocity of sound V in air is related to the frequency n of the sound and its wave-length λ . It is given by $V = n\lambda$.

The wave-length calculated above can be used *either* for calculating the velocity of sound in air, if the frequency is known *or* for calculating the frequency of the sound, when the velocity of sound in air is known.

Correction for temperature :—The velocity of sound in air increases with temperature. If V_t is the velocity of sound in air at $t^\circ\text{C}$, V_0 the velocity at 0°C , and α the volume coefficient of air,

$$V_t = V_0 \sqrt{1 + \alpha t} = V_0 \left(1 + \frac{1}{2} \alpha t \right)$$

as α is small.

Now, for air

$$\alpha = \frac{1}{273}$$

$$\therefore V_t = V_0 \left(1 + \frac{t}{546} \right)$$

$$\therefore V_0 = \frac{V_t}{1 + \frac{t}{546}} = \frac{V_t \times 546}{546 + t}$$

Correction for moisture :—The air column is saturated with moisture. So, its density is less than that of dry air. The following correction has to be applied :

$$V_{\text{dry air}} = V_{\text{moist air}} \sqrt{\left(\frac{760 - p + 0.6p}{760} \right)}$$

where p is the saturation vapour pressure at the temperature.

$$\therefore V_{\text{dry air}} = V_{\text{moist air}} \sqrt{\left(1 - \frac{0.4}{760} p \right)}$$

Tabulate the results as follows :

I. Laboratory temperature = 28.9°C.

Frequency of Tuning Fork	Length of Resonating air column		Wave length 2 (l ₂ - l ₁)	Velocity of Sound in air
	First length (l ₁)	Second length (l ₂)		
256	cms. 32.4 32.4 32.5 32.3	cms. 99.8 99.7 99.8 99.6	2 × 67.3 = 134.6 cms.	344.5 metres/sec.
Mean	32.4	99.7		
512	cms. 15.5 15.3 15.5 15.8	cms. 49.5 49.4 49.6 49.5	2 × 34.0 = 68.0 cms.	348.1 metres/sec.
Mean	15.5	49.5		
512	Second length (l ₂) cms. 49.5 49.4 49.6 49.5	Third length (l ₃) cms. 83.7 83.8 84.0 83.6	2 × 34.3 = 68.6 cms.	351.3 metres/sec.
Mean	49.5	83.8		

∴ The mean velocity of sound in air } = 348.0 metres per sec
at 28.9°C.

II. Correction for moisture :

Saturation vapour pressue of water at 28.9°c = 29.57 mm.

∴ Velocity of sound in dry } = 348 (1 - $\frac{0.4 \times 29.6}{2 \times 760}$)
air at 28.9°C

= $\frac{348 \times 754.1}{760}$ = 345.3 metres per sec.

III. Correction for temperature ;

$$\left. \begin{array}{l} \text{Velocity of sound in dry} \\ \text{air at } 0^{\circ}\text{C} \end{array} \right\} = \frac{345.3 + 546}{574.9} = 327.9 \text{ metres per sec.}$$

IV. End Correction :

$$C = \frac{l_2 - 3l_1}{2} = \frac{l_3 - 5l_1}{4}$$

l_1	l_2	l_3	C.
32.4 cms.	99.7 cms.	—	1.25
15.5 „	49.5 „	83.8 cms.	1.50
			1.55
		Mean ...	1.43

The mean diameter of the tube = 3.79 cms.

$$\therefore \frac{C}{d} = \frac{1.43}{3.79} = 3.38.$$

$$\therefore C = 0.38 d.$$

[The value of C varies from 0.3 d to 0.4 d depending on the nature of the mouth of the tube. For a long cylindrical tube with a plain rim, $C = 0.3 d$].

V. Assuming the velocity of sound in dry air at 0°C to be 330 metres per second, calculate its velocity in air saturated with water vapour at 28.9° . Use the value and calculate the frequencies of the tuning forks.

EXPERIMENT 44**VOLUME RESONATOR**

Aim :—To verify the relation between the volume of air and the frequency of the note that produces resonance in it.

Apparatus required :—Aspirator bottle, tuning forks of known frequency, measuring jar.

Procedure :—Take an aspirator bottle of 1 to 2 litres capacity having an opening at its side near the bottom. Fit it with an one-holed rubber stopper. Insert a short glass tube into the stopper and connect a rubber tube to it. Fit up a pinch-cock to the rubber tube.

Close the pinch-cock. Fill the aspirator bottle completely with water. Strike one of the tuning forks. Hold it near the mouth of the bottle and un-loosening the pinch-cock, slowly let out the water. The water level in the bottle falls. When the volume of air reaches a definite value, resonance is produced and a sharp loud note is heard. By adding water and letting it out, find the exact position, when the resonant note has the maximum intensity. Find the volume of air by adding water from a measuring jar to the bottle. Repeat the experiment two or three times and find the mean value of the volume of air which resounds to the note emitted by the particular tuning fork.

Repeat the experiment with other tuning forks. Find in each case the volume of air in which resonance is produced by the particular tuning fork.

Tabulate the results as follows :

Frequency of Tuning Fork n	Volume of the resonat- ing column of air v	$n^2 v$
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The values in the last column will be found to be constant.

The volume of air is inversely proportional to the square of the frequency of the note producing resonance in it.

EXPERIMENT 45

FREQUENCY OF A TUNING FORK BY THE FALLING PLATE METHOD

Aim :—To determine the frequency of a tuning fork using the Falling plate apparatus.

Apparatus required :—Falling plate apparatus, tuning fork, vernier microscope,

Description of Apparatus :—The Falling plate apparatus consists of a rectangular, upright wooden plank mounted on a base. The upright is provided with grooves on the two sides, through which a rectangular, glass plate can descend freely. The tuning fork is mounted in front of the plank on a suitable support with its prongs sloping upwards, towards the plank. A fine style is attached to one of the prongs of the fork. The support carrying the fork can be moved towards or away from the plank and the tuning fork clamped in such a position that the style just touches the glass plate, when it descends vertically down the grooves. To prevent the glass plate from breaking when it strikes the base board, some cotton or cork sheet is kept there.

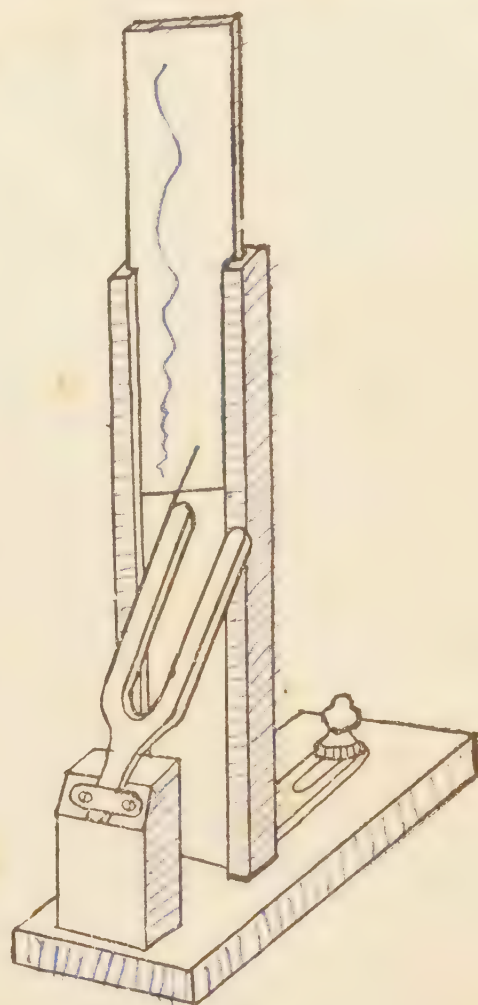


Fig. 78

Procedure :—Give a uniform coating of smoke on one side of the glass plate by waving it over the sooty flame of a bunsen burner or a kerosene or a turpentine lamp. Tie a thread across the top end of the glass plate. Insert it into the grooves with the smoked side outside and support it by the thread at such a height that its lower end is at the same level, as the top of the tuning fork. Adjust the tuning fork, so that the style just touches the glass plate.

When everything is ready, set the tuning fork in vibration and snap (or burn) the thread supporting the glass plate. As the glass plate descends freely, a wavy line is traced on the smoked surface by the style, due to the vibrations of the fork. With some dexterity and skill in manipulation, it is possible to get a neat trace on the plate.

Remove the glass plate. Draw the central line on the wavy curve with a fine pointed needle or pin.

Turn the microscope so that it is vertical. Adjust the eyepiece, so that the cross-wires are distinctly seen. Place the glass plate on the stage of the microscope. Focus the microscope on central line. Adjust the position of the plate, so that the line is parallel to the axis along which the microscope travels and the point of intersection of the cross-wires lies on the line.

Move the microscope, so that the point of intersection of the cross-wires coincides with any one of the points, where the wavy curve cuts the line, omitting the first few waves. Note the reading on the horizontal scale. Move the point of intersection of the cross-wires over an integral number of wave-lengths along the central line. Take the corresponding reading on the horizontal scale. Move it again over an equal number of wave-lengths and take the reading. Repeat till the whole central line is covered.

Calculations :—Let l_1 be the length on the central line corresponding to an integral number of waves, l_2 the length corres-

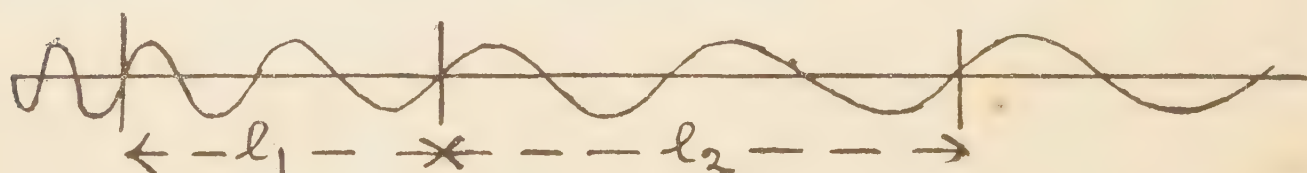


Fig. 79

ponding to the contiguous equal number of waves, x the number of waves in each group and n the frequency of the tuning fork, Then,

$$l_1 = ut + \frac{1}{2} gt^2$$

$$l_2 = (u + gt) t + \frac{1}{2} gt^2$$

$$\therefore l_2 - l_1 = gt^2 = g \left(\frac{x}{n} \right)^2$$

$$\therefore n^2 = \frac{gx^2}{l_2 - l_1}$$

$$\therefore n = x \sqrt{\frac{g}{l_2 - l_1}}$$

Tabulate the results as follows :—

Least count of the vernier microscope = cms.

No. of waves taken = x .

l_1	l_2	$l_2 - l_1$	$n = x \sqrt{\frac{g}{l_2 - l_1}}$
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∴ Mean frequency of the tuning fork =

The value obtained will be slightly less than the free frequency of the tuning fork, as the pressure of the style against the plate slightly reduces the frequency.

EXPERIMENT 46

KUNDT'S TUBE

Aim :—To determine (1) the velocity of sound in the rod of the Kundt's tube apparatus and (2) the Young's Modulus of elasticity of the rod.

Apparatus required :—Kundt's tube apparatus, dry cork powder, rods of different materials for use in the apparatus, samples of those rods.

Description of apparatus :—The Kundt's tube apparatus consists of a long glass tube about 120 to 150 cms. in length, and 3 to

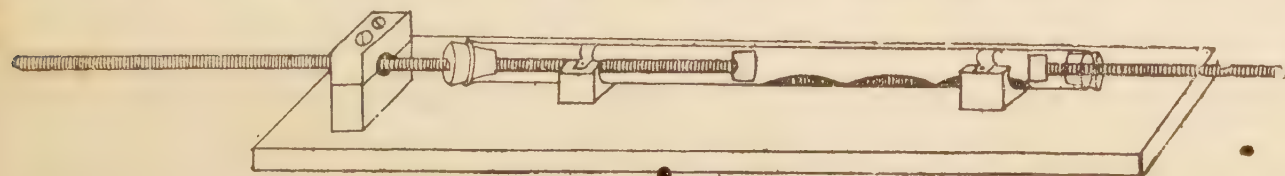


Fig. 80

4 cms. in diameter, mounted horizontally on two supports on a long base-board. From one side of it, a long rod, 150 cms. in length and of any material, like brass or wood or glass, is introduced. The end of the rod inside the tube is fitted with a cork or circular piece of wood whose diameter is slightly less than that of the tube. Just outside the mouth of the tube, on the base-board is fitted an arrangement for clamping the rod at its mid-point. This generally consists of a piece of wood screwed to the base-board with a semi-circular, transverse groove at its centre.

Another piece of wood with a similar groove is fixed on it by means of screws. The experimental rod passes through the central hole provided by the two grooves. At the other end of the glass tube, a shorter rod with a cork fitted at its end, is inserted.

Procedure :—Remove the glass tube from the apparatus and dry it thoroughly by warming it over a bunsen flame and sending a blast of air through it *or* by keeping it in the hot sunlight. Spread a continuous thin layer of dry cork powder, all along a metre scale, place the metre scale inside the tube and turn it upside down, so that the cork powder is transferred to the glass tube.

Fix the tube on the board. Introduce the long rod into the tube and clamp it tightly, exactly at its centre. Insert the shorter rod from the other side.

Stroke the end of the long rod *longitudinally*, so that it gives out its fundamental note. For stroking the rod, use a piece of

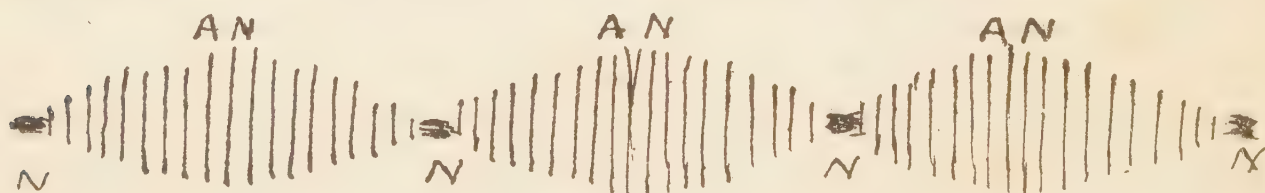


Fig. 81

leather or rough cloth dipped in resin powder. If the rod is a glass rod, use a piece of cloth soaked in methylated spirit. The vibrations of the rod produce stationary vibrations in the air column in the tube, if the distance between the end of the long rod inside the tube and the end of the short rod opposite is suitably adjusted. The end of the long rod is an *anti-node*, while the end of the rod opposite is a *node*. When the air column vibrates, the cork powder is violently agitated. When it settles down after the vibrations, *striations* or a *rib like pattern*, as in the figure, is produced all along the tube, between the rods. The ribs are longest at the anti-nodes and shortest at the nodes. Stroke the rod in quick succession and adjust the distance, till the maximum resonant sound is produced. The cork powder will have a tendency to move away from the anti-nodes and collect at the nodes.

When a clear and well defined pattern is obtained, find the mean length between two consecutive nodes. This is best done by measuring the length of N loops and dividing it by N .

Find the density of the sample rod, by weighing it in air and in water. The weight in air divided by the loss of weight in water gives its specific gravity, which is numerically equal to its density.

It can also be found out, by finding its volume and dividing the weight by volume.

Calculations :—When the rod emits its fundamental note, its central point is a node, while the two ends are anti-nodes. So, the wave-length of the note will be twice the length of rod. The wave-length of the note in the air in the tube will be equal to twice the distance between two consecutive nodes. Let L be the length of the rod ; l the distance between two consecutive nodes in the air column ; n the frequency of the note produced ; V , velocity of sound in the rod and v , velocity of sound in air. Then,

$$v = n \times 2l \quad \text{and} \quad V = n \times 2L$$

$$\therefore \frac{V}{v} = \frac{n \times 2L}{n \times 2l}$$

$$\therefore V = \frac{v \times L}{l}.$$

The velocity of sound in dry air at 0°C is 330 metres per sec. If the room temperature is t , then

$$v = 330 \left(1 + \frac{t}{546} \right)$$

$$\therefore V = \frac{330 \left(1 + \frac{t}{546} \right) \times L}{l}$$

$$= \frac{330 \times (546 + t) \times L}{546 \times l} \text{ metres/sec.}$$

Again, $V = \sqrt{\frac{q}{d}}$, where q is the Young's Modulus of the rod, d , its density and V , the velocity of sound in it.

$$\therefore V^2 = \frac{q}{d}$$

$$\therefore q = V^2 d.$$

Tabulate the results as follows :—

I. Length of rod (L) = 91.0 cms.

No. of loops	Length cms.	Length of each loop cms.
6	57.0	9.50
6	57.2	9.53
6	57.0	9.50
7	63.5	9.07
Mean		9.40 cms.

Mean distance between two nodes = 9.40 cms.

Velocity of sound in dry air at 0°C = 330 metres/sec.

Velocity of sound in dry air, at the } = $\frac{330 \times (546 + 34)}{546}$
room temperature, 34°C

= 350.5 metres/sec.

∴ Mean velocity of sound in the rod = $\frac{350.5 \times 91}{9.4}$

= 3393.1 metres/sec.

II. Young's Modulus of the material of the rod :—

Weight of the sample rod in air = 10.910 grams

Weight of the sample rod in water = 9.643 grams

∴ Specific gravity = $\frac{10.910}{1.267} = 8.017$.

∴ $q = V^2 d = (339310)^2 \times 8.017$
= 9.78×10^{11} dynes per sq. cm.

∴ Young's Modulus of the material (Brass) of the rod = $9.78 \times 10_{11}$ dynes/sq. cm.

EXPERIMENT 47

SONOMETER

(A) LAWS OF TRANSVERSE VIBRATIONS OF STRINGS

Aim :—To verify the Laws of transverse vibrations of strings with a sonometer.

Apparatus required :—Sonometer, tuning forks of different frequencies.

Description of apparatus :—In its usual form, the sonometer consists of a long, hollow rectangular box of some light wood, about 120 cms. long, 12 cms. broad and 10 cms. high. On the top, near each end, is fitted across the sonometer, a prismatic bridge with a metallic edge. Two short iron pegs are fixed at one

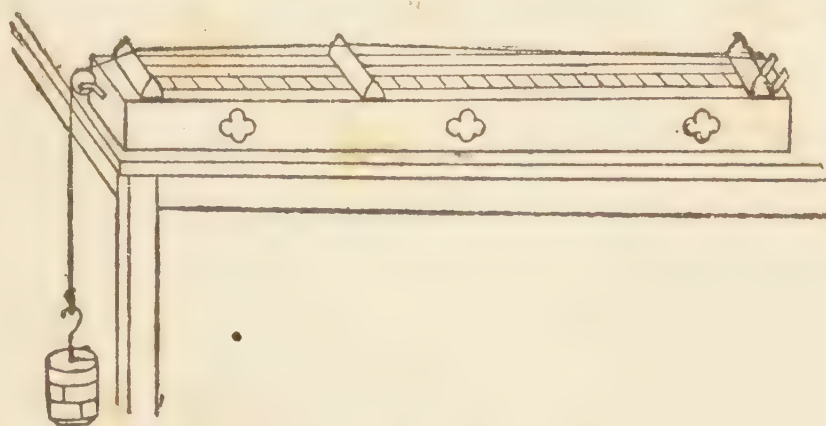


Fig. 82

end of it, to which wires can be fastened. At the other end, opposite to the pegs, are fixed two small, smooth, frictionless pulleys. The box has two or three circular openings on its sides. One or two movable bridges, similar to the fixed ones, are also provided. A metre scale is fitted on the top.

Procedure :—Fasten one end of a steel or brass wire to one of the pegs. Take it over the two fixed bridges and over one of the pulleys. Make a strong loop at the other end and hang from the loop a weight hanger. Add weights to the hanger. The wire gets stretched and the tension in it increases. Add two or three kilograms (slotted) weights to the hanger. The weights added will depend on the material and diameter of the wire.

Place the movable bridge under the wire, somewhere between the bridges, so that the stretched wire rests on that bridge also. Strike one of the tuning forks and place it on the sonometer box. Pluck the segment of the wire between the fixed bridge (near the pegs) and the movable bridge. Compare the notes given out by the tuning fork and the sonometer wire. Adjust the length of the vibrating segment of the wire by shifting the position of the movable bridge, so that the two notes are in unison.

If you have a good musical ear, the above adjustment is very easy. There are, however, some *mechanical* methods also for it. Produce both notes simultaneously. Judge which is higher and shift the bridge suitably, so that the two notes produce *beats* (rise and fall of sound). Make finer adjustments in the position of the bridge, so that the beats become longer and longer and ultimately

vanish. Then, the two notes are in perfect unison. The frequency of the vibrating segment of the wire is equal to the frequency of the tuning fork.

The detection of the beats also requires a musical ear to some extent. If even this is not possible, place on the wire a few light, paper riders (of the shape of inverted v). Strike the tuning fork and place it on the box. If the frequencies of the tuning fork and the stretched wire are of the same order, the wire will be set in *forced vibration*. Hence, the paper riders will begin to flutter due to the vibrations of the wire. Adjust the position of the movable bridge, so that the fluttering of the riders increases and ultimately, they are thrown off the wire. Replace the riders over and over again and adjust the length of the vibrating segment, so that they are thrown off, the moment the struck tuning fork is placed on the box.

[One precaution is essential at this stage. Place three or four paper riders at different places, *all along the wire* and see, if all of them are thrown off. The sonometer wire will be set in forced vibration, even if the frequency of the tuning fork is half or one-third of the natural frequency of the wire. But, in such cases, it will vibrate in more than one segment. (See fig). The frequencies of the tuning fork and of the wire are equal, *only* if the wire vibrates in *one* segment due to resonance.]

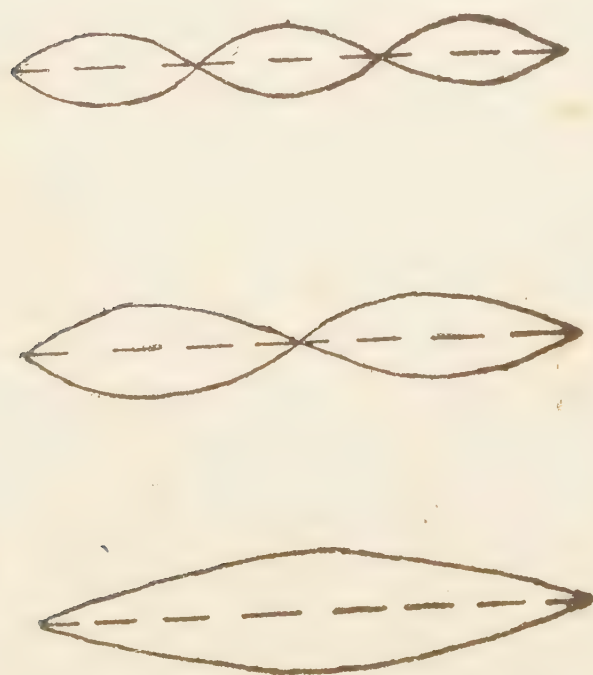


Fig. 83

There is one more delicate test to find out whether the tuning fork and the sonometer wire have identical frequencies. Place a sheet of white paper under the wire. Strike the tuning fork and place it on the box. The wire vibrates in resonance. If the adjustment is perfect, the movement of the wire is visible to the eye. Again, strike the tuning fork and place it on the box. After a few seconds, remove it and stifle its sound. If the adjustment is

perfect, the wire will take up the vibrations and a faint note will be heard.

Determine the lengths of the vibrating segment which are in unison with different tuning forks, keeping the tension constant.

For the same tuning fork, alter the tension of the wire and determine the lengths of the wire which are in unison with the tuning fork.

Keep the length of the wire constant and find the tensions of the wire, when it is in unison with different tuning forks.

Replace the wire by a wire of a different cross-section and repeat the experiment. Find the lengths of the vibrating segment of the wire in unison with different tuning forks, keeping the tension constant.

Determine the mass per unit length (or linear density) of each of the wires. This is done by finding accurately the weight of a measured length of the wire with a balance and dividing the weight by the length.

Laws of Transverse Vibrations of Strings:—When the segment of a wire, of length l , kept under tension T , vibrates, its frequency n is given by the formula,

$$n = \frac{1}{2l} \sqrt{\frac{T}{m}}$$

where m is the mass per unit length or linear density of the wire.

The relationships between the inter-connected quantities can be stated in the form of the following laws.

Laws of Transverse Vibrations:

(1) For the same wire, when the tension is kept constant, the frequency of vibration is *inversely* proportional to the length of the vibrating segment.

Or, when T is constant, nl is constant for a wire.

(2) For the same wire, when the frequency of vibration is constant, the length of the vibrating segment is *directly* proportional to the square root of the tension.

Or, when n is constant, $\frac{\sqrt{T}}{l}$ is constant.

(3) For the same wire, when the length of the vibrating segment is constant, the frequency of vibration is directly proportional to the square root of the tension.

Or, when l is constant, $\frac{\sqrt{T}}{n}$ is constant.

(4) For different wires, when the frequency of vibration and tension are constant, the length of the vibrating segment is inversely proportional to the mass per unit length (or linear density) of the wire.

Or, when n and T are constant, $l\sqrt{m}$ is constant.

Tabulate the results as follows:—

I. $T =$ grams weight ; $m =$ gms. per cm.

Frequency n	Length of vibrating segment l	nl
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II. $n =$; $m =$ grams per cm.

Tension in grams wt. T	Length of vibrating segment l	$\frac{\sqrt{T}}{l}$
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III. $l =$ cms. ; $m =$ grams per cm.

Frequency of vibration n	Tension in grams wt. T	$\frac{\sqrt{T}}{n}$
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IV. $T =$ grams wt. ; $n =$

Mass per cm. length m	Length of vibrating segment l	$l\sqrt{m}$
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(B) FREQUENCY OF A TUNING FORK

Aim:—To determine the frequency of a Tuning fork using the sonometer.

Apparatus required:—Sonometer, tuning Fork.

Procedure:—Fasten one end of a steel or brass wire to one of the pegs. Take it over the two fixed bridges and one of the pulleys. Form a strong loop at the other end and hang from it a weight hanger. Place 2 or 3 kilograms (slotted) weights on the hanger, so that the wire is stretched and under tension.

Place the movable bridge under the wire. Strike the tuning fork and place it on the box. Pluck the wire between the fixed bridge near the peg end of the box and the movable bridge. Compare the notes produced by the wire and tuning fork. Following the instructions given in the earlier experiment, adjust the length of wire so that the note produced by it is in *perfect unison* with the note produced by the tuning fork. Measure the length of the vibrating segment carefully with a scale.

Alter the tension by adding a $\frac{1}{2}$ or 1 kilogram to the hanger. Find the new length of the wire which will be in unison with the fork. Adding $\frac{1}{2}$ or 1 kilogram at a time, take half a dozen readings. The maximum safe weight to be added depends on the material and cross-section of the wire.

Replace the wire by another wire of a different linear density. Repeat the experiment and take half a dozen readings.

Find the weight of a measured length of each of the wires and determine accurately the mass per unit length (or linear density) of each wire.

Calculations :—The frequency n , of the vibrating segment of a wire, under tension T dynes, is given by the formula,

$$n = \frac{1}{2l} \sqrt{\frac{T}{m}}$$

where l is the length of the segment in cms. and m , the linear density in grams per cm.

Tabulate the results as follows :—

Mass per unit length of wire = m grams per cm.

Tension in dynes T	Length of vibrating segment l	$\frac{\sqrt{T}}{l}$
-------------------------	---------------------------------------	----------------------

The values in the last column are constant for the same tuning fork.

Find the mean value of $\frac{\sqrt{T}}{l}$. Substituting the values of m and $\frac{\sqrt{T}}{l}$ in the formula, $n = \frac{1}{2l} \sqrt{\frac{T}{m}}$, calculate n , the frequency of the tuning fork.

EXPERIMENT 48

MELDE'S STRING

Aim :—To verify the Laws of Transverse vibrations of strings by Melde's method and to determine the frequency of the tuning fork or vibrator.

Apparatus required :—Electrically driven tuning fork or vibrator, battery, rheostat, fine thread, scale pan, weights.

Description of apparatus :—The experiment is best performed with an electrically driven tuning fork or vibrator, since the

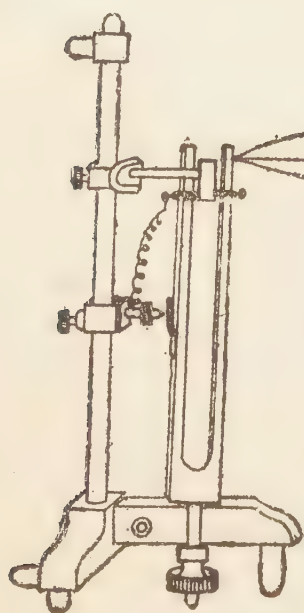


Fig. 84

vibrations are maintained automatically, for the duration of the experiment. The electrically driven tuning fork is mounted on a stand. A small, cylindrical electromagnet is introduced between the prongs of the fork at the top. Its size is such that the fork can vibrate freely without

touching the electromagnet. On the side of one of the prongs is attached a thin, brass plate with a platinum contact rivetted on it. Just opposite to this, there is an adjustable screw with a platinum contact at its tip, fitted to a clamp. This screw is insulated from the stand and has a terminal attached near it. There is another terminal somewhere on the stand. The coil of the electromagnet has two terminals, one of which is connected to the terminal attached to the screw. The other is connected through a battery, and a plug key to the terminal on the stand.

In the electrically driven vibrator, the arrangement is similar. The difference is that it has only one prong whose vibrations are maintained by a make and break electric arrangement.

Procedure :—Connect up the circuit consisting of a battery, a rheostat, a plug key and the coil of the electromagnet, through the

terminals on the stand and near the screw. Adjust the screw, so that it just touches the brass strip on the tuning fork. When contact is made, a current passes and the electromagnet is energised. The prongs are attracted inward. The contact is broken, the electromagnet loses its magnetism and the prongs fly back to their original position. This results in the contact being made again. The electromagnet is thus alternately energised and demagnetised. Consequently, the vibrations of the tuning fork are maintained automatically, without dying out. Adjust the rheostat, so that the vibrations are smooth and regular.

Break the circuit. Tie one end of a long, fine thread, about 3 to 4 metres long, to one of the prongs of the tuning fork. Pass the other end over a pulley mounted on a stand at a distance of over 3 metres from the tuning fork. Tie a light card-board scale pan to the end of the thread, on which small weights can be placed.

Turn the tuning fork, so that its vibrations are parallel to the string. Then, when the fork vibrates, *longitudinal* vibrations will be transmitted along the thread. Adjust the tension in the string, by adding small weights to the scale pan, and alter the distance between the fork and the pulley, such that stationary vibrations are set up in the string. A number of loops will make their appearance on the string. (See fig. 84.) The point where the string touches the pulley is a node. There will be a number of nodes and antinodes between the pulley and the tuning fork. By a finer adjustment of the tension, get well-defined and clear loops. [A loop is the distance between two nodes.] With a beam compass, measure the length of as many loops as possible and find the mean length of a loop.

By increasing the tension, the number of loops formed will decrease. Their lengths will increase. By decreasing the tension, the number of loops will increase and their lengths will decrease. There is a definite relation between the tension and the length of each loop. Take a number of readings, by altering the tension and measuring the mean length of a loop in each case.

Turn the fork, so that its vibrations are perpendicular to the string. *Transverse* vibrations will now be transmitted along the string.

As in the other position, adjust the tension and the distance between the fork and the pulley, so that clear, well-defined loops are formed on the string. Alter the tension and get loops of different lengths. Measure the tension and the length of the loop formed, as before.

Take a measured length of the string and find its weight accurately in a balance. Calculate the mass per unit length or the linear density of the string.

Theory :—When stationary vibrations are formed in a string under tension T , the length l of the vibrating loop is given by the following formula :

$$n = \frac{1}{2l} \sqrt{\frac{T}{m}}$$

where n is the frequency of the vibrations and m , the mass per unit length of the string.

In the *longitudinal* mode of vibration of the tuning fork, the frequency of the vibrating string is $\frac{1}{2}$ that of the tuning fork.

In the *transverse* mode of vibration of the tuning fork, the frequency of the vibrating string will be the same as that of the tuning fork.

From the readings taken, the relationships between n , l , T and m can be verified. If T , l and m are known, n can be calculated.

Tabulate the results as follows :—

I. *Longitudinal mode of vibration*

$$\text{Frequency of fork} = n.$$

$$\therefore \text{Frequency of string} = \frac{n}{2}.$$

$$\text{mass per cm. length of thread} = m \text{ grams per cm.}$$

Tension T dynes.	Length of n loops	Length of one loop l cms.	$\frac{\sqrt{T}}{l}$
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[The tension includes the weight of the scale pan.] The values in the last column are constant.

Use the formula,

$$n = \frac{1}{2l} \sqrt{\frac{T}{m}}$$

and calculate n and verify whether it agrees with the value marked on the fork.

II. *Transverse mode of vibration :*

Frequency of fork = n .

$\therefore$ Frequency of string = n .

mass per cm. length of thread = m grams per cm.

Tension T dynes.	Length of n loops	Length of one loop l cms.	$\frac{\sqrt{T}}{l}$
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[The tension includes weight of scale pan.]

The values in the last column will be constant.

Use the formula $n = \frac{1}{2l} \sqrt{\frac{T}{m}}$ and calculate n . Verify whether it agrees with the value marked on the fork.

Graph :—Draw a graph representing $\sqrt{T}$ along the X axis and the length of a loop along the Y axis in each case. You will get a straight line graph. It can be used for finding the value of an unknown load.

PART II

Light

Magnetism

Electricity

PART II
SECTION V
LIGHT
EXPERIMENT 49
PHOTOMETERS

Aim :—To compare the illuminating powers of two sources of light using (1) the Bunsen's Photometer, (2) the Jolly's Photometer and (3) the Lummer-Brodhun Photometer.

Apparatus required :—Bunsen's Photometer, Jolly's Photometer, Lummer-Brodhun Photometer, two sources of light of different illuminating powers.

(A) Bunsen's Photometer

Description :—The Bunsen's Photometer consists of a circular disc of unglazed paper, mounted on a vertical stand. At the centre of the disc, there is a circular grease spot. The grease spot is more translucent than the rest of the disc and so allows more of the light falling on it to pass through, while the rest of the disc allows little or no light falling on it to pass through. Consequently, in reflected light, the grease spot appears darker than the rest of the paper, while in transmitted light, it appears brighter.



Fig. 85

Procedure :—All experiments with photometers must be performed in a dark room. Place the Bunsen's photometer at the centre of the table. Place the two sources of light to be compared on either side of it. The line joining the two sources must pass normally through the photometer. It is absolutely essential that no light, other than that from the two sources, should fall on the photometer.

The grease spot generally appears either darker or brighter than the rest of the paper. This is due to the fact that the

fraction of the light reflected and the fraction transmitted is different for the grease spot and for the rest of the disc. Move the photometer, so that the grease spot appears indistinguishable from the rest of the disc. This happens when the light transmitted through the photometer from left to right is compensated by the light transmitted through it from right to left. This will be the case when the *intensities of illumination* on the disc due to the two sources are exactly equal.

In other words,

$$\frac{I_1}{d_1^2} = \frac{I_2}{d_2^2} \quad (\text{where } I_1 \text{ and } I_2 \text{ are the illuminating powers of the two sources}).$$

$$\therefore \frac{I_1}{I_2} = \frac{d_1^2}{d_2^2}.$$

One difficulty that is encountered is that, if the grease spot appears indistinguishable when looked at from one side, it is distinctly seen, when looked at from the other side. This is due to the difference in the absorption of light when it passes through the disc. This is remedied by mounting by the side of the disc two plane mirrors equally inclined, say, at 45° to the plane of the disc, so that the two sides of the disc can be seen simultaneously. Then, adjust the distances of the sources so that the appearance of the grease spot is the same in both the images.

Measure the distances d_1 and d_2 of the two sources from the grease spot. Rotate the photometer through 180° and repeat the experiment. Alter the distances and take half a dozen readings.

Tabulate the results as follows :—

Sources of light—Electric bulbs of different wattages.

Distance of disc from one source d_1	Distance of disc from the other source d_2	$\frac{I_1}{I_2} = \frac{d_1^2}{d_2^2}$
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$$\therefore \text{Mean } \frac{I_1}{I_2} =$$

(B) Jolly's Photometer

Description :—The Jolly's Photometer consists of a compound block made up of two identical slabs of clear paraffin wax, free from air bubbles, separated by a sheet of tin-foil. This is mounted

on a stand and placed between the two sources of light to be compared, so that the paraffin blocks on either side of the tin-foil face the sources.

Procedure :—Place the stand with the Jolly's Photometer at the centre of the table. Place the two sources of light to be compared, one on either side of the photometer, along the central normal passing through it. The two slabs face the two sources of light. Since the tin-foil stops the light from passing through, the illumination of the paraffin block on either side of it is due to the light falling on it from the respective source and getting scattered. So, the two paraffin blocks appear differently illuminated, when observed from the side, with the tin-foil forming the line of demarcation. Adjust the distances of the sources, till the two blocks appear equally bright. It will be so, if the intensities of illumination at the two faces are equal.



Fig. 86

Measure the respective distances of the sources of light from the faces of the block. Rotate the photometer through 180° and repeat the experiment. Alter the distances and adjust again, so that the two blocks appear equally bright. Measure the distances. Take half a dozen readings.

Tabulate the results as follows :—

Distance of block from one source d_1	Distance of block from the other source d_2	$\frac{I_1}{I_2} = \frac{d_1^2}{d_2^2}$
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$$\therefore \text{Mean } \frac{I_1}{I_2} =$$

(3) Lummer-Brodhun Photometer

Description :—This is an accurate form of photometer. It consists of a thin white disc of magnesium carbonate M, mounted in such a manner, that its two faces receive light from the two

sources to be compared. The diffused light from the faces passes through two reflecting prisms and enters a telescope incorporated at the side of the photometer. So, in the field of view of the telescope there are two regions, differently illuminated, each region corresponding to the light received from one of the faces. When the faces of the disc are equally illuminated, the two regions in the field of the view of the telescope become indistinguishable from each other.

The arrangement of the prisms is shown in the figure. 1 and 2 are two right-angled total reflection prisms mounted on the sides

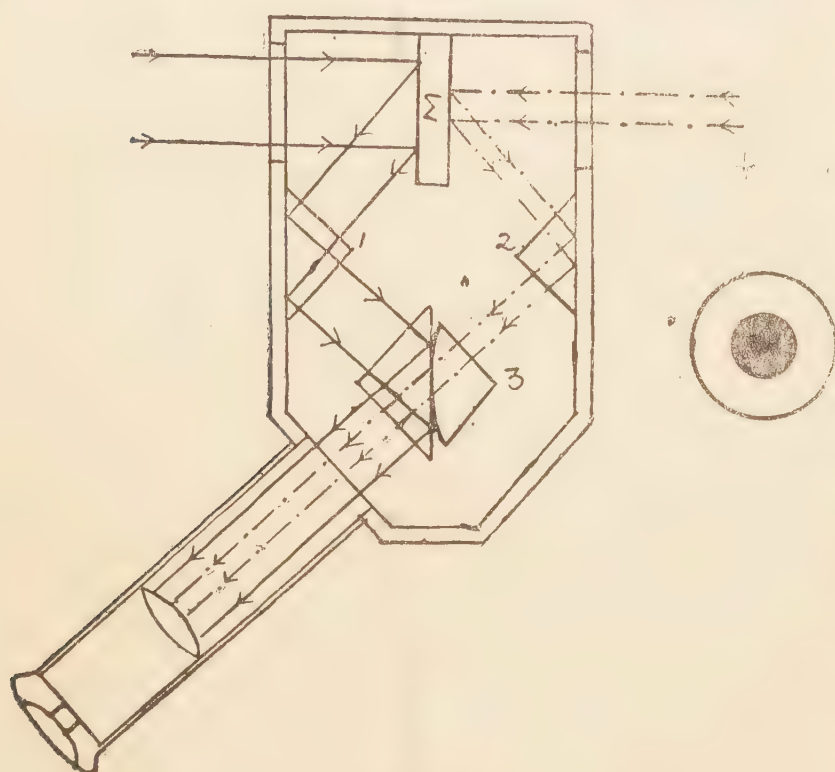


Fig. 87

of the photometer. Each prism receives light from one of the faces of the disc M and totally reflects it. The two reflected beams fall on the sides of a double prism 3, from different directions. The double prism consists of two right-angled prisms, placed with their hypotenuses in contact. One of these is rounded off, so

that only a small circular portion at the centre of it is in contact with the other prism. Rays of light incident at this portion pass through, while light falling on the rest of the hypotenuse is totally reflected. The path of the rays of light is indicated in the diagram. The light that enters the telescope consists of (1) rays of light diffused from one of the faces of the disc M and passing through the central portion of the double prism and (2) rays of light diffused from the other face of the disc M and totally reflected from the hypotenuse of one of the prisms constituting the double prism.

Procedure :—Mount the photometer at the centre of the table. Place the two sources of light on either side of it, so that

the light from each source falls normally on one of the faces of the disc M in the photometer. Look through the telescope and adjust the eye-piece so that the field of view is in clear focus. The appearance presented will be a circular patch at the centre surrounded by a circular ring. (See inset in fig.). The patch at the centre and the ring may not be equally bright. When the two become indistinguishable from one another, it means, that the intensities of illumination on the two faces of the disc are equal. Adjust the distances, so that the two regions merge into one another. Measure the distances. Turn the photometer through 180° , so that the faces of the disc get inter-changed. Adjust the distance of one of the sources, if necessary, so that the two regions in the field of view merge into one another. Measure the distances. Alter the distances and repeat the experiment. Take half a dozen readings.

Tabulate the results as follows :—

Distance of one source from disc M d_1	Distance of the other source from disc M d_2	$\frac{I_1}{I_2} = \frac{d_1^2}{d_2^2}$
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$$\text{Mean } \frac{I_1}{I_2} =$$

EXPERIMENT 50

REFRACTIVE INDICES OF SOLIDS AND LIQUIDS (BY DIRECT REFRACTION)

Aim :—To determine the refractive indices of solids and liquids (1) by the parallax method and (2) using the vernier microscope.

Apparatus required :—Rectangular glass slab, tall beaker, glass cube, cylindrical or cubical glass basin, tall pins, vernier microscope, lycopodium powder, liquid, drawing board.

(A) PARALLAX METHOD

(1) REFRACTIVE INDEX OF A GLASS SLAB

(a) Object kept close to slab

Procedure :—Fasten a sheet of white paper on the drawing board. Place the glass slab on it and draw its outline. Make a

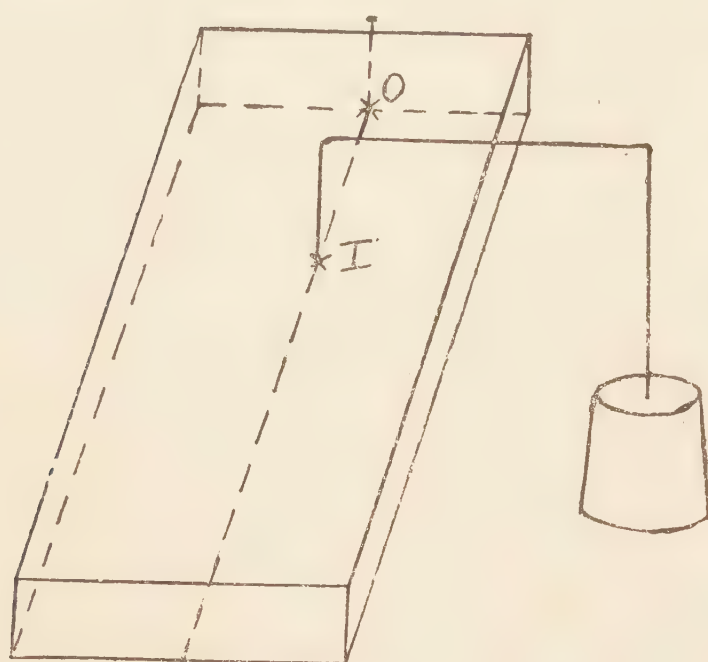


Fig. 88

mark O, on one of the sides and draw a normal at the point. Replace the slab on the outline drawn. Fix a pin on the mark O, close to and touching the slab. Take a knitting needle and bend it twice at right angles, so that one of the parallel arms is shorter than the other. Insert the longer arm into a cork. Move the cork, so that the shorter

arm just touches the top surface of the slab, over the normal drawn from O. Look through the slab at the image of the pin and adjust the cork, so that the needle above the slab appears to be a continuation of the image of the pin. Move the eye to and fro and further adjust the needle, so that they do not separate. In other words, there must be no parallax between the image of the pin and the needle. Then, they will be at the same distance from the eye. Measure the distances of the pin and the needle from the opposite face.

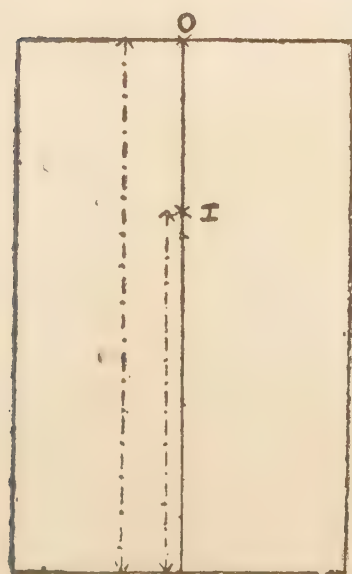


Fig. 89

Repeat the experiment and measure the distances again.

Use the other two faces of the slab, repeat the experiment and take readings. Then,

$$\left. \begin{array}{l} \text{Refractive} \\ \text{Index of slab} \end{array} \right\} = \frac{\text{Distance of object O (pin) from opposite face}}{\text{Distance of image I (needle) from opposite face}}$$

Tabulate the results as follows :—

Distance of object from opposite face d_1 cms.	Distance of image from opposite face d_2 cms.	Refractive Index $\mu = \frac{d_1}{d_2}$
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Note :—The distance of the object from the opposite face is termed the *actual distance*, while the distance of the image from the opposite face is termed the *apparent distance*.

(b) Object kept at a distance from the slab

The object pin may be placed at a distance from one face of the slab and its refracted image, seen through the opposite face, located. The only difference is that a different formula must be used for calculating the refractive index.

Place the glass slab on the sheet of paper fixed to the drawing board. Draw its outline. Draw a normal to one of the faces of the slab, extending to some distance from the slab. Replace the slab on the outline. Fix a pin O on the normal drawn, at a distance of about 3 to 5 cms. from the face of the slab. Look through the slab and locate the position of its image I, on the normal, using the bent pin, by the parallax method. Measure the thickness t of the slab and the distance t' between the object O and the image I. Then, if μ is the refractive index of the slab,

$$t' = t \left(1 - \frac{1}{\mu} \right)$$

$$\text{or } \mu = \frac{t}{t - t'}$$

Alter the position of the object pin and repeat the experiment. Take half a dozen readings.

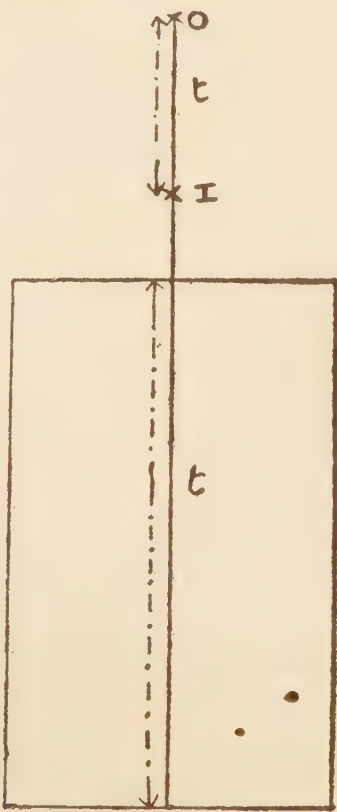


Fig. 90

Tabulate the readings as follows :—

Distance of object pin from slab cms.	Distance of image from slab cms.	Distance between object and image t' cms.	Thickness of slab t cms.	Refractive Index $\mu = \frac{t}{t - t'}$
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∴ Average Refractive Index =

(2) REFRACTIVE INDEX OF A LIQUID

Procedure :—Take a tall beaker. Place a bright pin P, at the bottom of the beaker. Pour the liquid into the beaker to a height of 10 to 15 cms. Cover the sides of the beaker by black paper.

Mount a bright pin Q horizontally on a clamp fitted to a stand.

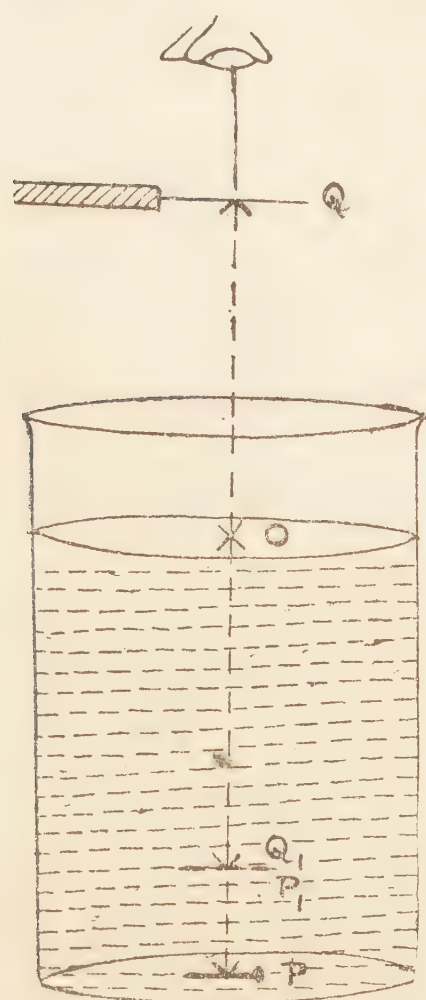


Fig. 91

[If a tubular light with a straight filament and of low wattage is available, the lighted filament will be better than a pin for locating the position of the image.]

Look from above and adjust the clamp so that the pin Q is parallel to the image of pin P in the liquid. Keep the eye in the vertical plane containing the two pins. Adjust the height of the pin Q so that its virtual image Q_1 seen by reflection at the surface of the liquid and the refracted image P_1 of the pin P, inside the liquid coincide without parallax. Measure the distance QO of the pin from the surface O of the liquid. It will be equal to the distance of the refracted image of the pin P in the liquid, from its

surface. Measure the height PO of the liquid in the beaker. Alter the height of the liquid in the beaker and repeat the experiment. Take half a dozen readings.

$$\left. \begin{array}{l} \text{Refractive Index} \\ \text{of liquid} \end{array} \right\} = \frac{\text{Height of pin Q from the surface of the liquid.}}{\text{Height of the liquid in the beaker}}$$

Tabulate the results as follows :—

Height of liquid in the beaker PO cms	Distance of pin Q from surface of the liquid QO cms	Refractive Index $\mu = \frac{PO}{QO}$
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∴ Mean Refractive Index =

(B) VERNIER MICROSCOPE**(1) REFRACTIVE INDEX OF A GLASS CUBE**

Procedure :—Turn the microscope so that its axis is vertical. Adjust the eye-piece, so that the cross-wires are seen distinctly. Determine the least count of the vernier. Sprinkle a few grains of lycopodium powder on the stage of the microscope. Raise or lower the microscope so that the grains of the lycopodium powder are in clear focus. Note the reading on the main vertical scale and add to it the vernier reading (the coinciding vernier division multiplied by the least count). Let this be a . Place the glass cube or slab on the powder. Raise the microscope so that the powder is again in clear focus. Note the reading as before. Let it be b . Sprinkle a few grains of lycopodium powder on the top of the cube or slab. Raise the microscope so that the lycopodium grains are again in clear focus. Note the reading. Let it be c . Then,

$$\text{Actual thickness of cube} = c - a$$

$$\text{Apparent thickness of cube} = c - b$$

$$\therefore \text{Refractive index of glass cube} = \frac{c - a}{c - b}$$

Take two or three sets of readings.

Tabulate the readings as follows :—

$$\text{Each main scale division} = 0.05 \text{ cms.}$$

50 vernier divisions are equal to 49 scale divisions.

$$\therefore \text{Each vernier division} = 0.049 \text{ cms.}$$

$$\therefore \text{Least count of vernier microscope} = 0.001 \text{ cms.}$$

$$\left. \begin{array}{l} \text{Reading when microscope is focussed} \\ \text{on the lycopodium placed on the} \\ \text{stage of the microscope} \end{array} \right\} = 1.923 \text{ cms.}$$

$$\left. \begin{array}{l} \text{Reading when microscope is focussed} \\ \text{on the refracted image of the lyco-} \\ \text{podium, with the cube or slab} \\ \text{placed on it} \end{array} \right\} = 2.605 \text{ cms.}$$

$$\left. \begin{array}{l} \text{Reading when microscope is focussed} \\ \text{on the lycopodium on the top of the} \\ \text{cube or slab} \end{array} \right\} = 3.953 \text{ cms.}$$

$$\begin{aligned} \therefore \text{Refractive Index of glass slab or cube} &= \frac{3.953 - 1.923}{3.953 - 2.605} \\ &= 1.507. \end{aligned}$$

(2) REFRACTIVE INDEX OF A LIQUID

Procedure :—Make the initial adjustments in the microscope as in the previous experiment. Place the glass basin on the stage of the microscope. Place a small bright pin or needle at the bottom of the basin and fix it with a piece of wax. Focus the microscope on the *tip* of the pin. Note the reading on the vertical scale. Let it be a . Pour the liquid into the vessel to a height of 2 to 3 cms. If the pin is fixed with wax, it will not be displaced. Focus the microscope on the refracted image of the pin. Take the reading on the vertical scale. Let it be b . Sprinkle a few grains of lycopodium dust on the surface of the liquid. Focus the microscope on the grains and take the reading. Let it be c . Then,

$$\begin{aligned} \text{Actual depth of liquid} &= c - a \\ \text{Apparent depth of liquid} &= c - b \\ \therefore \text{Refractive Index of liquid} &= \frac{c - a}{c - b} \end{aligned}$$

Alter the height of the liquid by adding a little more of the liquid and take the readings corresponding to (1) the refracted image of the pin and (2) the top of the liquid surface. Repeat for 2 or 3 different depths of the liquids and take readings.

Take another liquid and repeat the experiment.

Tabulate the results as follows :—

$$\begin{aligned} \text{Each main scale division} &= 0.05 \text{ cm.} \\ \left. \begin{array}{l} \text{Each vernier scale division (50 vernier scale} \\ \text{divisions are equal to 49 main scale} \\ \text{divisions)} \end{array} \right\} &= 0.049 \text{ cms.} \\ \therefore \text{Least count of vernier} &= 0.001 \text{ cms.} \\ \left. \begin{array}{l} \text{Reading when microscope is focussed on} \\ \text{bottom of basin (tip of pin)} \end{array} \right\} &= 9.589 \text{ cms.} \\ \left. \begin{array}{l} \text{Reading when microscope is focussed on} \\ \text{the refracted image of pin under water} \end{array} \right\} &= 10.037 \text{ cms.} \\ \left. \begin{array}{l} \text{Reading when microscope is focussed on} \\ \text{the top surface of water} \end{array} \right\} &= 11.467 \\ \therefore \text{Refractive Index of water} &= \frac{11.467 - 9.589}{11.467 - 10.037} \\ &= \frac{1.878}{1.430} = 1.313. \end{aligned}$$

Tabulate likewise for other readings.

EXPERIMENT 51

REFRACTIVE INDICES OF SOLIDS
AND LIQUIDS

(BY CRITICAL ANGLE METHOD)

Aim :—To determine the refractive index of (1) a glass prism and (2) a liquid by measuring their critical angles.

(A) Glass Prism

Apparatus :—Glass prism, drawing board, pins.

Procedure :—The glass prism used is an equilateral prism of side 5 to 7.5 cms. Fix a sheet of paper to the drawing board. Place the prism on it and mark its outline. Let A, B, C, represent the vertices of the prism. Replace the slab on the outline. Fix a pin on AC at D, at a distance of about 1.5 cms. from A. Look at the image of the pin, through the face BC. Slowly move the position of the eye towards C. The image of the pin will vanish after a certain distance. Keeping the eye in the position in which the image *just* vanishes, fix two pins at E and F, so that the feet of the

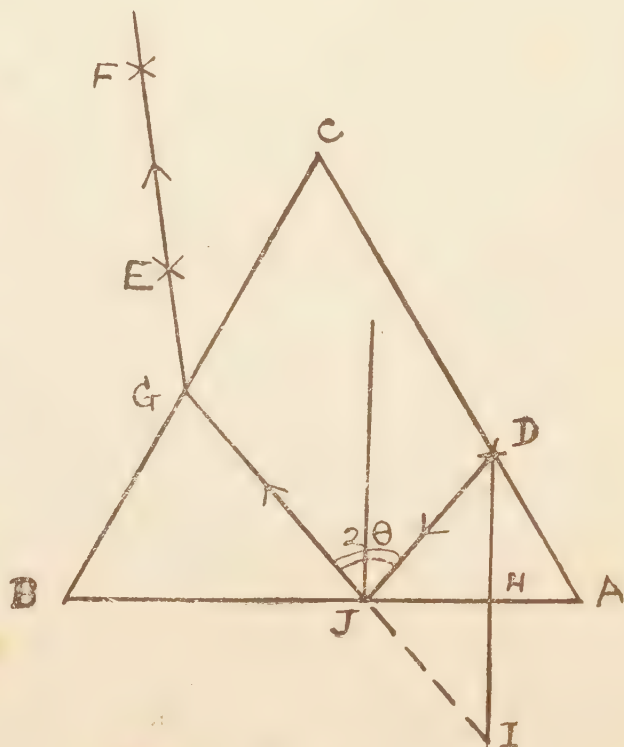


Fig. 92

two pins and the foot of the image of the first pin. are in the same straight line. If all the pins are kept vertical, then the two pins and the image of the first pin will be in the same vertical plane. Remove the prism and the pins. Join EF and produce it to meet BC at G. From D, draw a normal DH to AB and produce it. Mark on it a point I, such that $HI = DH$. Join GI. Let it cut AB at J. Join DJ. Measure the angle DJG. It will be equal to twice the critical angle for the material of the prism. Let it be 2θ . Then, the critical angle will be equal θ .

$$\text{Refractive Index of the material of the prism} = \frac{1}{\sin \theta}$$

Repeat the experiment, fixing the first pin at a different point on AC. Find the critical angle. Take 3 or 4 readings.

Light rays from the pin D fall on the face AB of the prism. All the rays falling on face AB between A and J are refracted by the face AB. All the rays falling on face AB between J and B are totally reflected. It must be remembered that the ray of light incident at the critical angle *just* grazes the surface AB after refraction. So, the angle DJG is really *slightly greater than twice the critical angle*.

Tabulate the readings as follows :—

Angle DJG 2θ	Critical angle θ	Refractive Index $\mu = \frac{1}{\sin \theta}$
------------------------	----------------------------	---

$\therefore$ Mean Refractive Index =

(B) Refractive Index of a liquid

Apparatus required :—Mounted air-cell, cubical glass trough, sodium light.

Description of apparatus :—The air-cell consists of two plane-parallel glass plates, of equal breadth, one of them being a little longer than the other. They are separated from each other by a thin strip of tin foil placed round the edges and cemented together, so as to be water tight. There is a thin film of air between the plates. It is fitted inside a hydrostatic bench, so that it is vertical. To the sides of the bench, two pins are fixed horizontally at their bottom, at the centre, with their axes in the same straight line. The whole arrangement is such that when the bench is placed on the table, the air-cell remains vertical, with its lower edge about half a cm. above the surface of the table.

Procedure :—The cubical glass trough used must have plane, parallel sides. Place it on a sheet of paper fixed to a drawing board. Draw its outline. Remove it. Draw a normal through the centres of one pair of sides. Replace the trough. Pour the given liquid into it to about three-fourths of its height. Immerse the air-cell at the middle of the trough, with the air-cell

parallel to the sides of the trough, for which the normal has been drawn. Mount a narrow, vertical rectangular slit parallel to one of these sides, at a distance of 5 to 10 cms. from it. The axis of the slit should lie on the normal drawn. Illuminate the slit with sodium light. Fix a pin on the normal on the other side of the trough. Keeping your eye along the line joining the pin and the slit, rotate slowly the hydrostatic bench about a vertical axis passing through the centre of the air cell. In a particular position, the slit will be covered by a dark shadow creeping towards it. Without moving the position of the eye, rotate the bench so that the vertical pin coincides with the edge of the shadow. Mark the points A, D, opposite to the ends of the pins fixed to the hydrostatic bench.

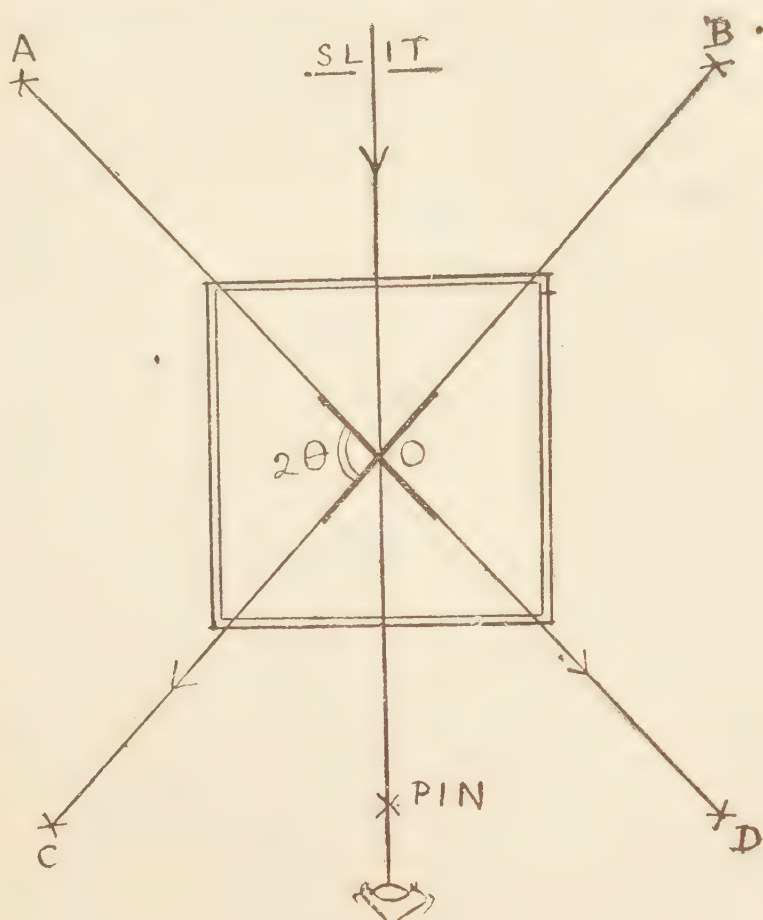


Fig. 93

Rotate the hydrostatic bench in the opposite direction and find the position on the other side of the normal, where the pin coincides with the edge of the shadow. Mark the points B, C, opposite to the pins fixed to the hydrostatic bench.

Remove the hydrostatic bench and the trough. Join the two pairs of points marked. Let them be AD and BC. Let them intersect at O. The angle AOC gives twice the critical angle. Measure the angle AOC and calculate the critical angle θ .

Repeat the experiment twice or thrice and find the mean critical angle.

$$\text{Refractive Index of liquid} = \frac{1}{\sin \theta}$$

Let PO represent the direction of the incident ray when the slit is just covered by the shadow. Then PO is incident at the

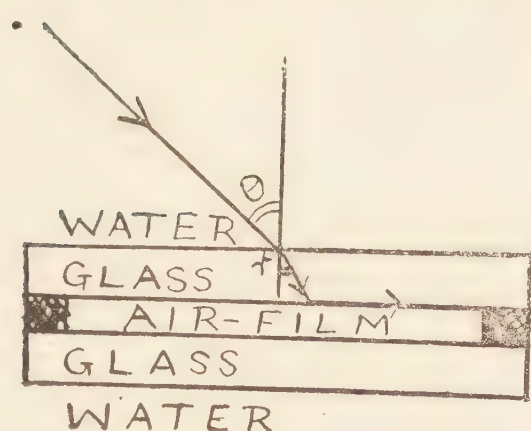


Fig. 94

air film at the critical angle. So, the angle between PO and AD or BC is $(90 - \theta)$, and the angle AOB is $(180 - 2\theta)$. Hence, the angle AOC is 2θ . Total reflection occurs actually at the glass air surface. θ is the angle of incidence at the water-glass surface. Let r be the angle of incidence at the glass-

air surface, in the limiting position. Then,

$$\frac{\sin \theta}{\sin r} = w \mu_g \text{ and } \frac{\sin r}{\sin 90} = g \mu_a$$

$$\therefore \frac{\sin \theta}{\sin r} \times \frac{\sin r}{\sin 90} = w \mu_g \times g \mu_a$$

$$= w \mu_a$$

$$\therefore a \mu_w = \frac{1}{\sin \theta}$$

Tabulate the results as follows :—

Trial No.	Angle AOC 2θ	Critical angle θ	Refractive Index $\mu = \frac{1}{\sin \theta}$
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[The arrangement described here is the simplest type in use and is not capable of giving very accurate results. There are other types, however, in which better arrangements are made for measuring the critical angle to a higher degree of accuracy.]

EXPERIMENT 52

FOCAL LENGTHS OF CONCAVE AND CONVEX MIRRORS

Aim :—To determine the focal length of (1) a concave mirror and (2) a convex mirror.

Apparatus required :—Concave mirror, convex mirror, mounted knitting needles, unframed plane mirror, convex lens, stands for the mirrors and the lens.

(A) Concave mirror

Procedure :—Mount the concave mirror *vertically* on a suitable stand, so that its axis is *horizontal*. Turn the concave mirror so as to receive the rays from any distant object. Catch the clear real image of the distant object formed by reflection at the mirror, on a white screen. Measure the distance of the screen from the centre of the mirror. It will give the *approximate focal length* of the mirror.

Place a mounted knitting needle P, in front of the mirror. It is desirable to have the tip of the needle painted white. Adjust its

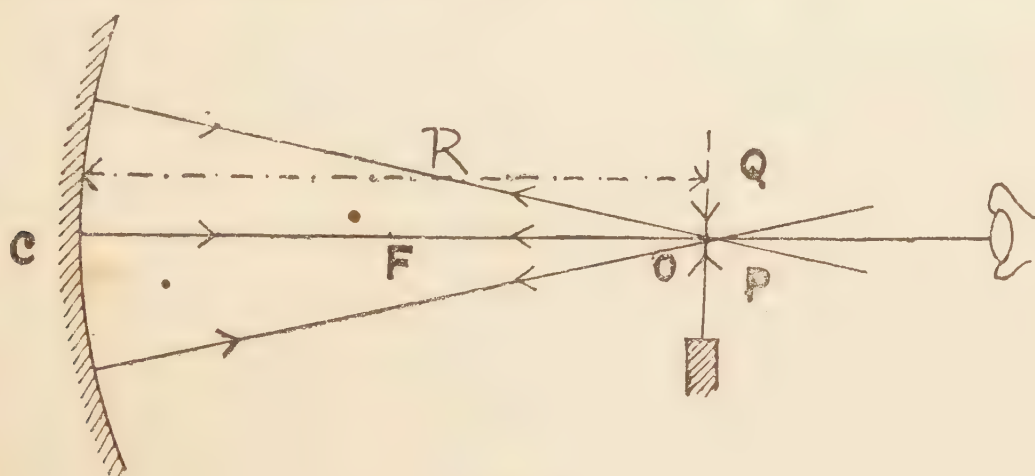


Fig. 95

height, so that its tip lies on the principal axis of the mirror. Move it to and fro in front of the mirror, until you are able to see its real, inverted image, when you look towards the mirror. Adjust the position of the needle, so that it coincides with its image and there is no parallax between the two, when the eye is moved from side to side. [A mounted eye-piece can be used to verify the correctness of the adjustment. Look through it at the needle and the image. If both of them are seen in clear focus, at the same time, they are in the same vertical line.] Measure the distance of the needle from the centre of the mirror along the principal axis. It will give the *radius of curvature of the mirror* (r).

U-V method—Place the knitting needle P a little beyond the principal focus of the mirror. Look towards the mirror from a sufficiently large distance. You will see a real, inverted and highly magnified image of the needle. Place a second mounted needle Q similar to the first, in front of the mirror with its tip on the principal axis. Move it to and fro, till its tip coincides with the tip of the inverted image of the first needle and there is no parallax

between them, as the eye is moved from side to side. Measure the distances u of the first needle and v of the second needle,

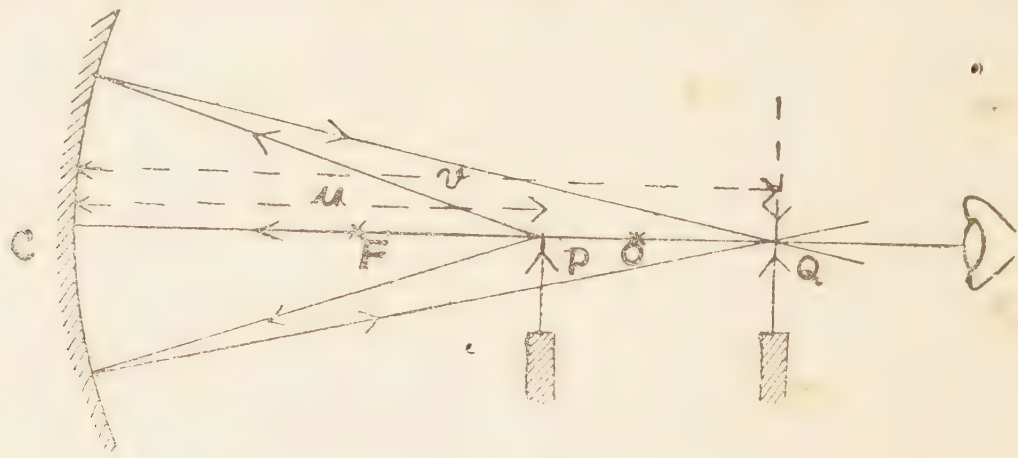


Fig. 96

from the centre of the mirror, along the principal axis. Increase the distance of the first needle from the mirror by 5 cms. Its image will move towards the mirror. Locate its position, using the second needle, by the parallax method. Measure u and v as before. Repeat the experiment by increasing u by 5 cms. at a time and locating the corresponding position of the image each time, by the parallax method, using the second needle. Take 6 to 8 readings. The values of u must be such, that as many of them are less than r , as are greater than r .

If u and v are the distances of an object and its image from the centre of a concave mirror, measured along its principal axis,

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \text{ or } \frac{2}{r}$$

where f is the focal length and r , the radius of curvature of the concave mirror. From the readings taken, calculate r .

Tabulate the results as follows :—

- (1) Approximate focal length of the concave mirror by focussing a distant object } = cms.
- (2) Radius of curvature using a single needle = cms.
- (3)

Distance of object from mirror u . cms	Distance of image from mirror v . cms	$\frac{1}{u}$	$\frac{1}{v}$	$\frac{1}{v} + \frac{1}{u}$ $= \frac{1}{f}$	Focal length f . cms
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$\therefore$ Mean focal length of concave mirror = cms.

$\therefore$ Radius of curvature = cms.

Graphs :—(1) Represent u along the X axis and v along the Y axis, taking the same scale for both, with the origin representing zero for both. Plot the points and draw a smooth curve thorough them. You will get a hyperbola. Draw the bisector of the angle at the origin. Find the values of u and v corresponding to the point of intersection of the curve and the bisector. They will be equal. Each of them will be equal to $2f$.

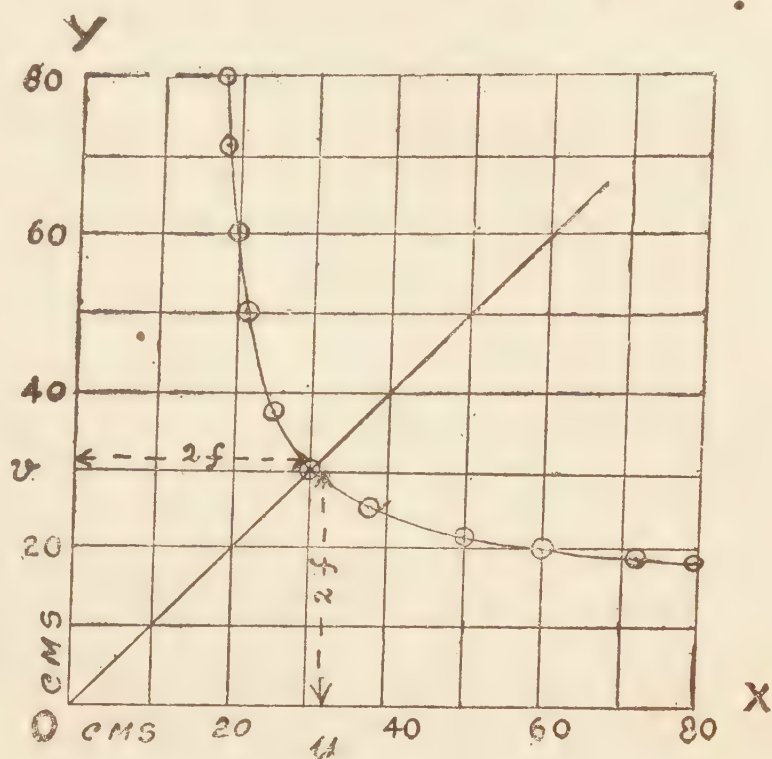


Fig. 97

(2) Represent $\frac{1}{u}$ along the X axis and $\frac{1}{v}$ along the Y axis, taking the same scale in both. The graph obtained will be a straight line. Produce it both ways to meet the X and Y axes. The point of intersection of the line with either axis will give $\frac{1}{f}$.

Note:—The paral-
lax method adopted in
the above experiment is
accurate and can be
used for both real and
virtual images. How-
ever, it involves strain
for the eye. So, it is
usual to use an illumi-
nated cross-wire or a
piece of wire-gauze,
fitted at the centre of
a screen mounted on a
stand, as the object.
The image is caught

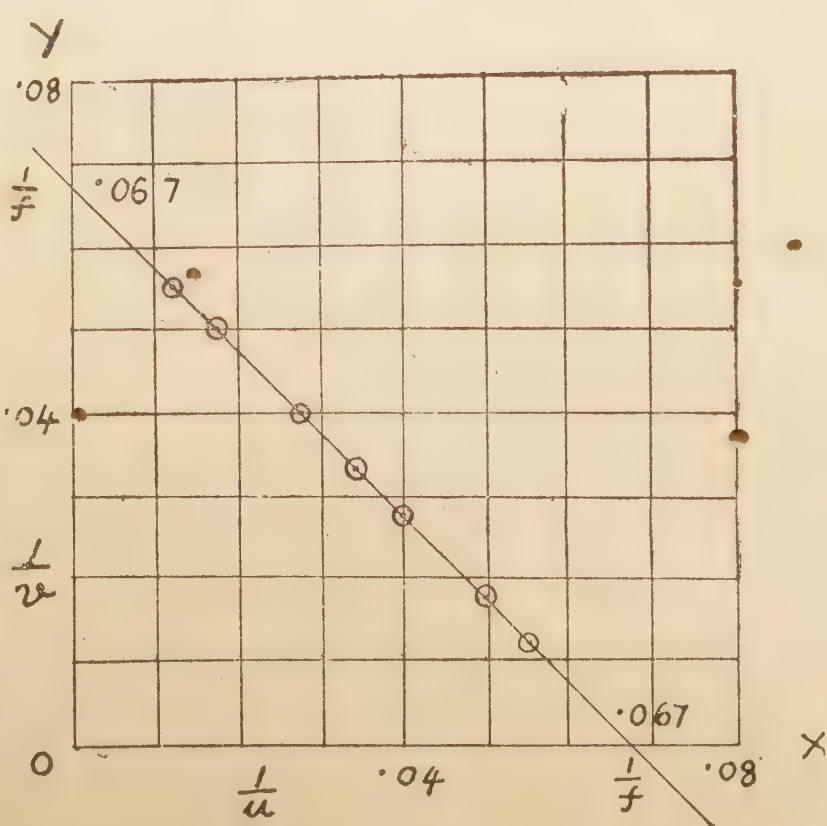


Fig. 98

on a white card-board screen or a ground-glass plate mounted on a stand. The object screen is placed at various distances from the concave mirror. The image screen is adjusted, so that a clear well-defined image is formed on it, corresponding to each position of the object. u and v are measured and f and $2r$ calculated as explained already.

(b) Convex mirror

Procedure :—(1) $u - v$ method—A convex mirror produces only a *virtual* image, behind it, whatever be the position of the object in front of it. The virtual image formed behind the mirror can be located only by the parallax method. To do this with ease, an unframed plane mirror strip mounted *vertically* on a stand is used.

Mount the convex mirror *vertically* on a stand, so that its axis is *horizontal*. Place the stand with the plane mirror M in front

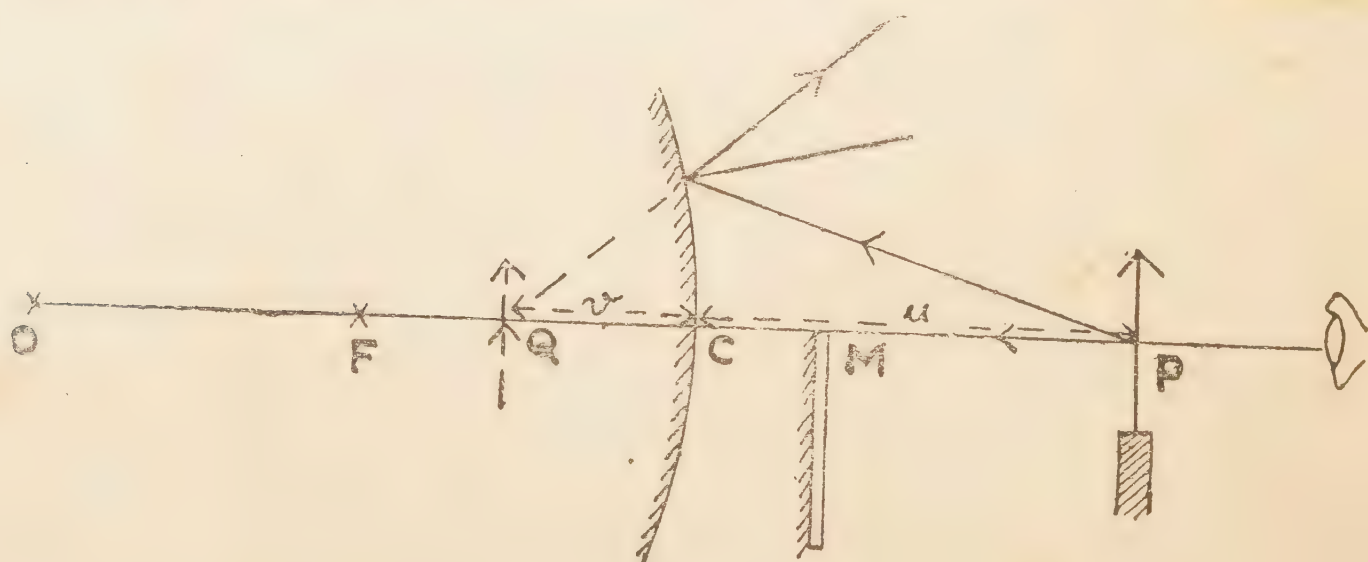


Fig. 99.

of it facing the same direction. Adjust its height so that its top horizontal edge lies on the principal axis of the convex mirror. Place the mounted knitting needle P in front of the mirrors. It must be in the vertical plane passing through the principal axis of the convex mirror. Look towards the mirrors and adjust its position so that a virtual image of the needle formed by reflection at the plane mirror and another virtual image formed by reflection at the convex mirror are both visible. Make further adjustments, so that the two virtual images coincide and there is no parallax between them, as the eye moves from side to side.

The virtual image Q formed by the plane mirror is as far behind it, as the object is in front of it. So, the distance MP of the

needle from the plane mirror *minus* the distance MC between the mirrors will give the distance CQ between the convex mirror and the virtual image formed by it. Thus, u and v being known, f can be calculated from the formula $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$. It must be borne in mind that, since the image is virtual, v is *negative*.

Alter the positions of the plane mirror and the needle and take half a dozen readings. The values of u may be adjusted to range from 10 cms. to 50 cms.

Tabulate the readings as follows :—

Distance between object and convex mirror u cms	Distance between convex mirror and plane mirror a cms	Distance between image and convex mirror $v = (u - a)$ cms	$\frac{1}{v}$	$\frac{1}{u}$	$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$	Focal length f cms
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$\therefore$ Mean focal length of convex mirror = cms

(2) *Determine f using an auxiliary convex lens :—*Mount a convex lens whose focal length is greater than that of the convex

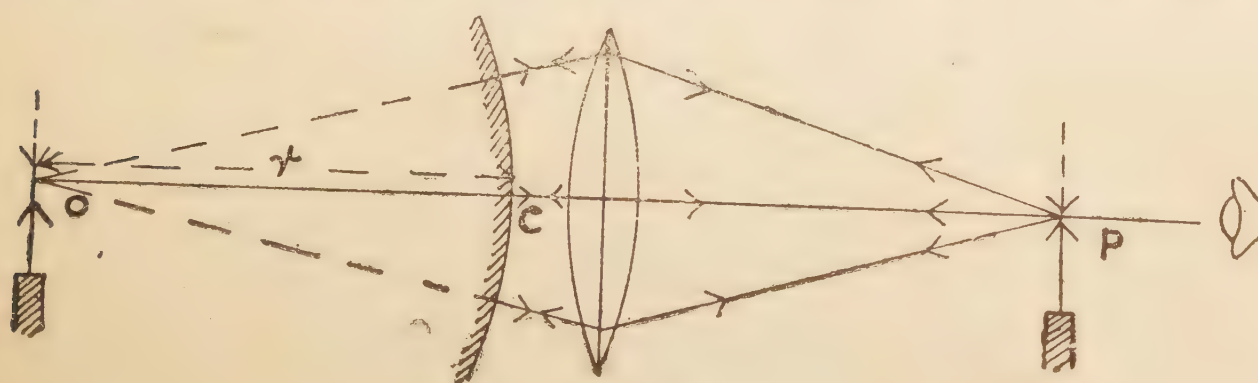


Fig. 100

mirror on a lens stand, with its axis *horizontal*. Place P one of the mounted needles, a little beyond the principal focus of the lens. Adjust its height, so that its tip lies on the principal axis of the lens. A real, inverted, magnified image of the needle will be formed on the other side of the lens, on the principal axis. The distances of the object and the image from the lens must be nearly equal. Using the second needle Q, locate the position of the image, by the parallax method.

Interpose the convex mirror, so as to face the lens, between the second needle and the lens. The principal axes of the lens and

the mirror should be along the same line. Rays of light refracted by the lens, get reflected from the convex mirror, pass through the lens and form an image on the same side of the lens as the object. Look towards the lens from the side of the first needle P. Move the convex mirror to and fro, till the real, inverted image of the needle formed, coincides with the needle and there is no parallax between the two. If the rays after passing through the lens, fall normally on the convex mirror, they will retrace their path and form a real, inverted image by the side of the object. Hence, it is obvious that the second needle must be at the centre of curvature of the convex mirror. Measure the distances between (1) the lens and the second needle and (2) the lens and the convex mirror. The difference will give the radius of curvature r of the convex mirror.

Alter the position of the first needle. Repeat the experiment. Take 3 or 4 readings.

Tabulate the results as follows :—

Distance between first needle from lens u. cms	Distance between second needle and lens v cms	Distance between lens and convex mirror x cms	Radius of curvature of mirror $r = (v - x)$. cms
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$\therefore$ Mean radius of curvature = cms.

EXPERIMENT 53

FOCAL LENGTHS OF CONVEX AND CONCAVE LENSES

Aim :—To determine the focal length of (1) a convex lens and (2) a concave lens.

Apparatus required :—Convex lens, concave lens, mounted needles, mounted plane mirror, lens-stands, telescope.

(A) Convex lens

Procedure :—(1) **Focussing a distant object :—**Mount the convex lens on a lens-stand with its axis *horizontal*. Turn the lens to receive the rays from a distant object. Place a white screen on the other side of the lens and catch the image of the distant object on it. Adjust it, so that a clear, well-defined

image is formed on it. Measure the distance between the centre of the lens and the screen, along its principal axis. It will give the approximate focal length of the lens. The more distant the object chosen, the more accurate the result will be.

(2) **u — v method** :—Place a mounted needle P, on one side of the convex lens, just beyond its principal focus. Adjust its

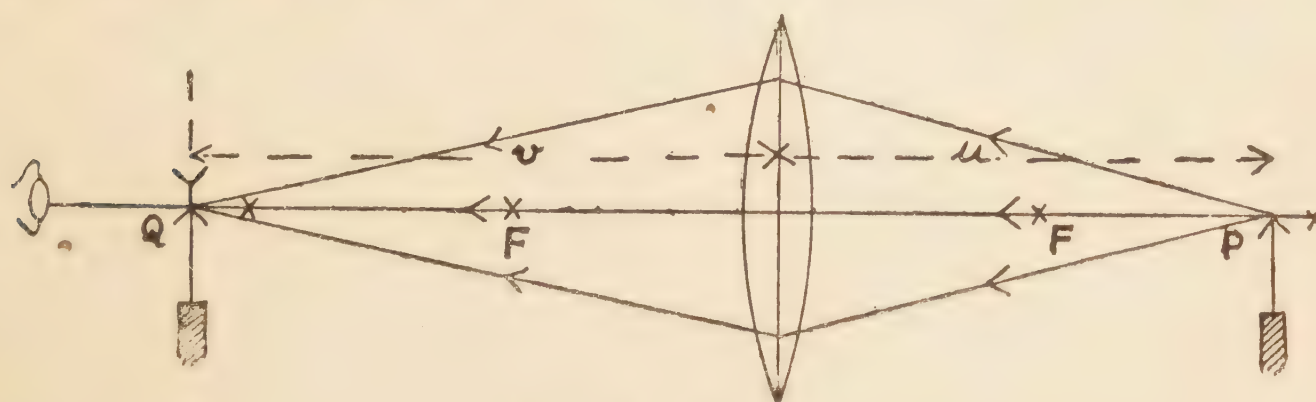


Fig. 101

height so that its tip is on the principal axis of the lens. Look towards the lens from the other side and observe the real, inverted image of the first needle. Place the second needle Q, in such a position that its tip coincides with the tip of the image. Adjust its position, so that there is no parallax between the two, as the eye is moved from side to side. Measure the distance u of the first needle P, from the centre of the lens, along the principal axis and the distance v of the second needle Q, likewise.

Move the first needle P, away from the lens by about 5 cms. Find the position of its image on the other side, using the second needle Q, by the parallax method. Measure u and v . Repeat the experiment, increasing u by 5 cms. at a time and take half a dozen readings.

Calculate f , using the formula, $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$. [Follow the convention that when the image is real, the distance is *positive* and when it is virtual, it is *negative*.]

Tabulate the results as follows :—

Distance of object from lens u cms	Distance of image from lens v cms	$\frac{1}{v}$	$\frac{1}{u}$	$\frac{1}{v} + \frac{1}{u}$ $= \frac{1}{f}$	Focal length f cms
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$\therefore$ The mean focal length of the lens = cms.

Graphs :—(1) Draw a graph representing u along the X axis and v along the Y axis taking the same scale on both the axes, with the origin as zero. The curve will be a hyperbola. Draw the bisector of the angle at the origin. The co-ordinates of the point of intersection of the bisector with the $u - v$ curve will give $2f$. See fig 97.

(2) Draw another graph, representing $\frac{1}{u}$ along the X axis and $\frac{1}{v}$ along the Y axis, taking the same scale on both axes. You will get a straight line graph. Produce it both ways to meet the two axes. The points of intersection will give $\frac{1}{f}$. See fig 98.

(3) **Displacement method :—**Place the two needles P and Q at a distance l apart which is greater than $4f$. Interpose the convex

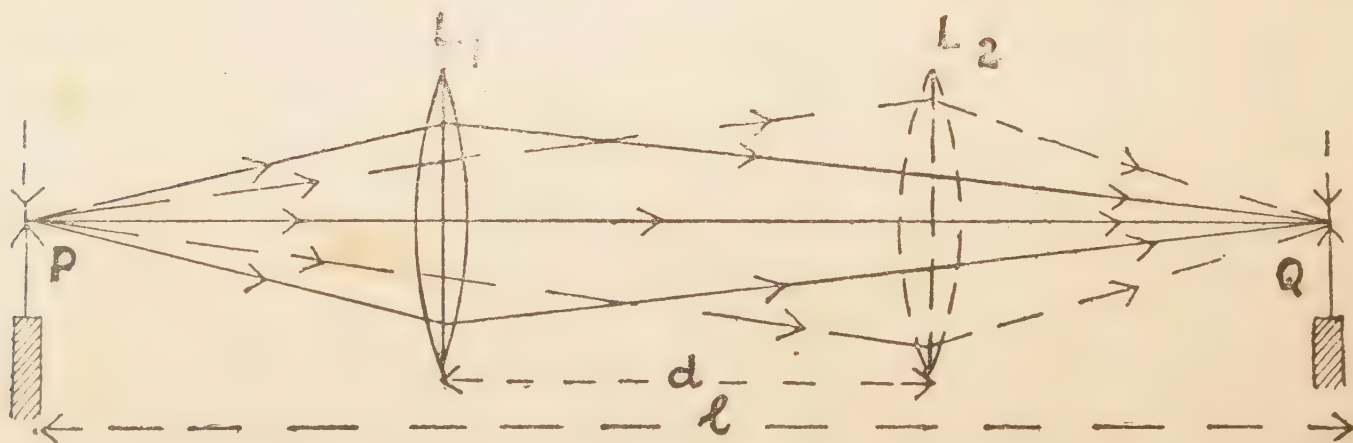


Fig. 102

lens between the two needles, so that its principal axis passes through the tips of the two needles. Looking towards the lens from one side, move it to and fro, till a real, inverted image of the needle on the other side of the lens is observed by the eye. Adjust the position of the lens, so that this image coincides with the needle near the eye and there is no parallax between the two, as the eye is moved from side to side. Measure the distance between the centre of the lens and one of the needles along the principal axis.

Without disturbing the needles, move the lens away from or towards the needle near the eye, so that the inverted image of the needle on the other side of the lens again coincides with the needle near the eye. Adjust the lens so that there is no parallax between the two. It will be noticed that, if the former image is magnified,

the latter image will be diminished and *vice versa*. Measure the distance between the centre of the lens and the same needle, along the principal axis. The difference between the two readings will give the distance d through which the lens has been moved.

Alter the distance l between the two needles by 10 cms., at a time and repeat the experiment. Take three or four readings.

The focal length of the lens is calculated from the formula

$$f = \frac{l^2 - d^2}{4l}.$$

Tabulate the results as follows :—

Distance between needles l cms	Distance of lens from first needle		Distance between the two positions $d_1 - d_2 = d$ cms	$\frac{l^2 - d^2}{4l} = f$ cms
	in position I d_1 cms	in position II d_2 cms		

∴ Mean focal length = cms.

(4) **Using a plane mirror** :—Place a mounted plane mirror close to the lens, parallel to it and facing it. Place a needle P on

the other side of the lens, with its tip on its principal axis. Look towards the lens from the side where the needle is placed. Rays of light from the needle after refraction through the lens, fall on the plane mirror and get

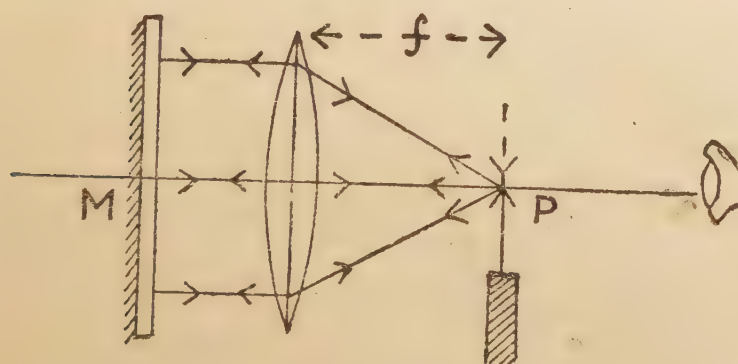


Fig. 103

reflected. The reflected rays pass through the lens and form a real, inverted image. Adjust the position of the needle so that it coincides with its own image and there is no parallax between the two, as the eye is moved from side to side. Measure the distance between the needle and the centre of the lens along the principal axis. It will give the focal length of the lens. Disturb

the arrangement and repeat the adjustment. Take two or three readings and find the mean value of f .

This method is suitable for both short and long focus lenses.

(5) **Using an auxiliary convex lens :—**Methods 1 to 3 are *not* suitable for convex lenses of long focal lengths (of more than

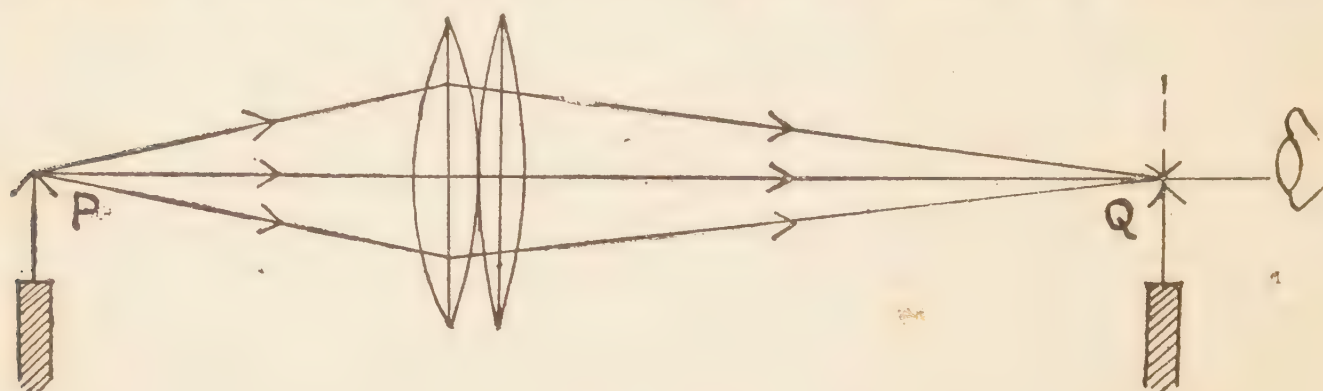


Fig. 104

one metre). The focal lengths of such lenses can be determined using a short focus convex lens, by the following methods.

(a) Determine the focal length f_1 of the short focus lens alone by the $u-v$ or the displacement methods.

Combine the two lenses and determine the focal length F of the combination by the same methods.

If f_1 and f_2 are the focal lengths of the two lenses, and F , the focal length of the combination,

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

Substituting the values of F and f_1 , calculate f_2 .

(b) Place P, one of the needles on one side of the short focus lens at a distance greater than its focal length. Adjust it, so

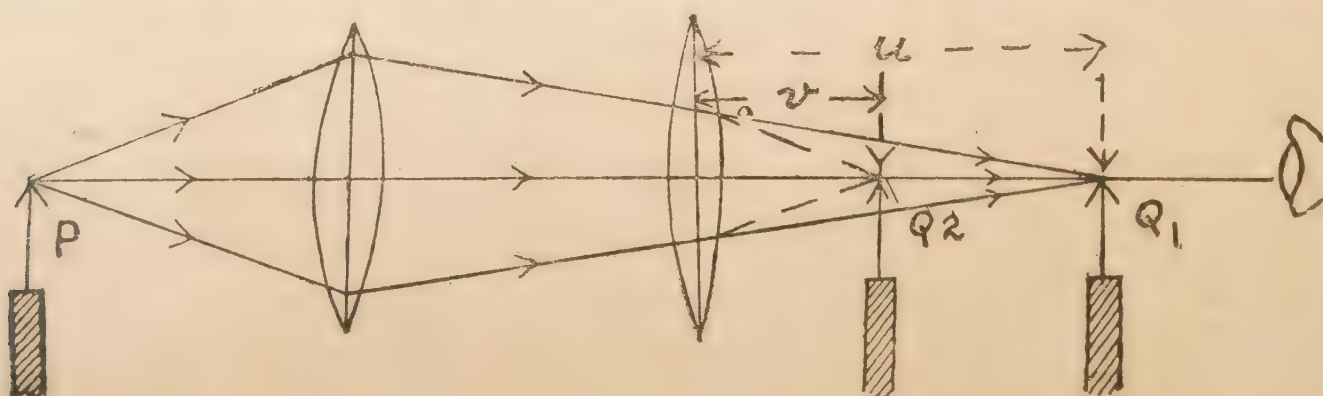


Fig. 105

that its tip lies on the principal axis of the lens. Look towards the lens from the other side and locate the position Q of the real

inverted image of the needle P by the parallax method, using the second needle. Measure the distance d_1 between the second needle and the lens along the principal axis. Interpose the long focus convex lens between the other lens and the second needle, so that the principal axes of the two lenses coincide. The second needle will no longer coincide with the image of the first needle, without parallax. Move it towards the lenses and adjust it, so that it again coincides with the image Q_2 of the first needle, without parallax. Measure the distance d_2 , between the short focus lens and the needle and the distance d , between the two lenses along the principal axis.

The short focus lens produces a convergent beam by refraction. This convergent beam is rendered more convergent by the long focus lens. Hence, the first image is the *virtual* object for the long focus lens.

$$\therefore u = (d_1 - d)$$

$$\text{and } v = (d_2 - d)$$

[u is *negative* since it is the distance of the *virtual* object.]

Substitute the values of u and v in the formula

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \quad \text{and calculate } f.$$

Take three or four readings by changing the relative positions of the lenses and calculate f .

Tabulate the results as follows :—

Distance between short focus lens and first image d_1 cms	Distance between short focus lens and second image d_2 cms	Distance between lenses d cms	$u = d_1 - d$ cms	$v = d_2 - d$ cms	$\frac{1}{u}$	$\frac{1}{v}$	$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$	Focal length f cms

$\therefore$ Mean focal length = cms.

(6) Using a Telescope—Auto-Collimation

This method is eminently suitable for determining the focal lengths of the value of one metre and more. Any short range telescope with cross-wires fitted to its eye-piece can be used.

Adjust the eye-piece so that the cross-wires can be distinctly seen. Mount a brightly illuminated scale at a distance of about 15 to 20 metres from the telescope. Adjust the telescope so that the divisions on the scale are seen clearly in the telescope, coinciding with the cross-wires, without parallax.

Attach the long focus lens firmly to the objective lens in the telescope with some wax. Move the combination towards the scale. Find the position when the scale divisions are again seen clearly in the telescope, coinciding with the cross-wires, without parallax.

Measure the distance from the centre of the long focus lens to the scale along its principal axis. It will give the focal length of the lens.

(B) Concave lens

Procedure :—A concave lens always produces only a *virtual* image. Hence, a direct determination of the focal length is out of the question. Using an auxiliary short focus convex lens, or a concave mirror, the focal length can be determined.

(a) Using an auxiliary convex lens

(1) Choose a convex lens whose focal length f , is less than that of the concave lens, so that when the two are placed in contact, the combination will be convex.

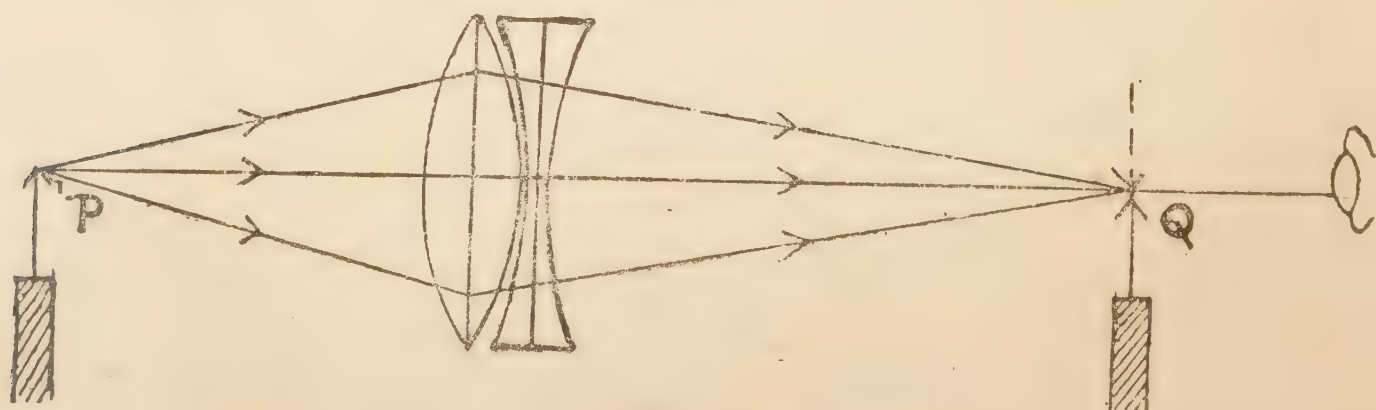


Fig. 106

Find the focal length of the convex lens, by the $u-v$ or the displacement method, already described. Take six readings and find the mean value of f .

Place the two lenses in contact. Determine the focal length F of the combination, by the $u-v$ or the displacement method. Take six readings and find the mean value of F .

The focal length of the combination of two lenses is given by the formula,

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

F and f_1 being known, calculate f_2 .

(2) Place a mounted needle P on one side of the convex lens, beyond its principal focus, with its tip on its principal axis. Look towards the lens from the other side of the lens. Adjust the second needle so that its tip coincides with the tip of the real, inverted image Q of the first needle. Measure the distance d_1 between the second needle and the convex lens.

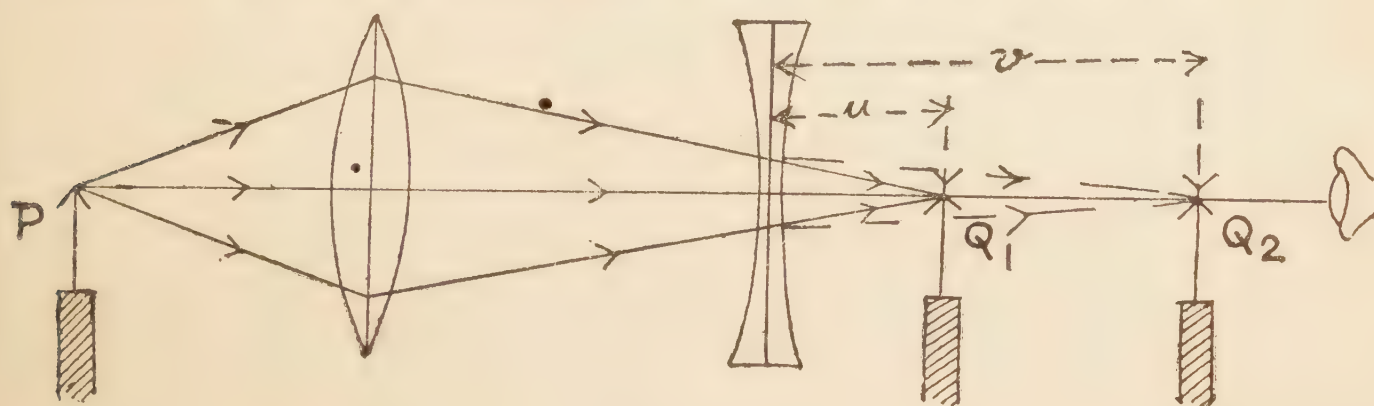


Fig. 107

Interpose the concave lens between the convex lens and the second needle, so that the principal axes of the two lenses coincide and the distance between the concave lens and the second needle is less than its focal length. The convergent beam falling on the concave lens becomes less convergent and so, the image is formed at a more distant point. Move the second needle away from the lens and adjust it, so that its tip coincides with the tip of the image Q_2 , without parallax. Measure d_2 , the distance between the convex lens and the second needle and d , the distance between the two lenses. Now,

$$\begin{aligned} u &= d_1 - d \\ \text{and } v &= d_2 - d. \end{aligned}$$

Since, the object is *virtual*, u is *negative*. Calculate f , using the formula,

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

Changing the positions of the lenses and the first needle, take six readings.

Tabulate the results as follows:—

Distance between convex lens and first image d_1 cms	Distance between convex lens and second image d_2 cms	Distance between lenses d cms	$d_1 - d = u$ cms	$d - d_2 = v$ cms	$\frac{1}{v}$	$\frac{1}{u}$	$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$	Focal length f cms
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Mean focal length = cms.

(b) Using an auxiliary convex lens and a plane mirror :
Mount the convex lens with its axis horizontal. Place one of the

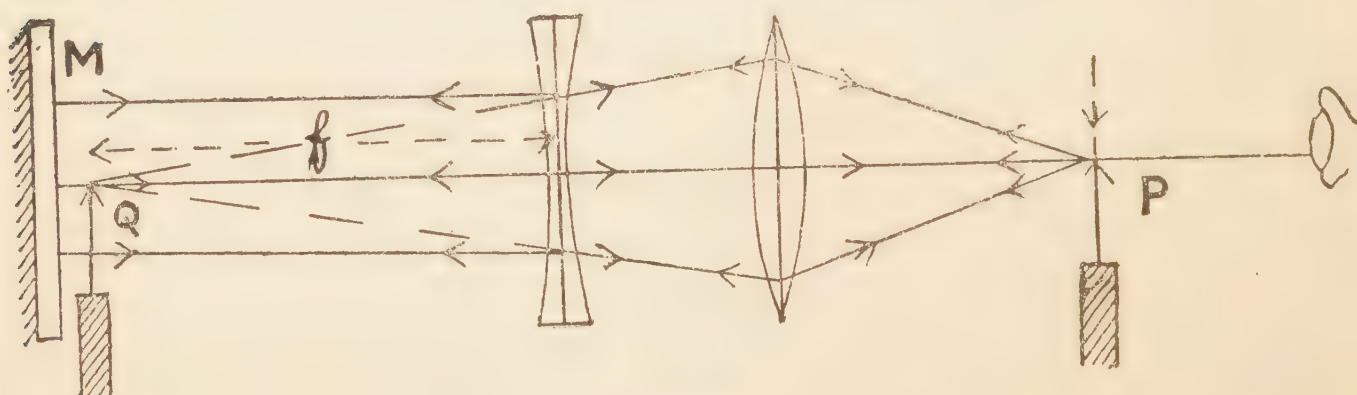


Fig. 108

needles P on one side of it, with its tip on the principal axis of the convex lens. Look towards the lens from the other side. Placing the second needle Q between the eye and the lens, adjust its position so that its tip coincides with the tip of the inverted image of the first needle, without parallax. Now, place a plane mirror facing the convex lens and parallel to it, just beyond this point. Look towards the lens from the side, where the first needle P is placed. Interpose the concave lens between the convex lens and the mirror, so that their axes coincide. Move it to and fro, till the image of the first needle formed by the combination of the convex lens, concave lens and the plane mirror coincides with the needle, and there is no parallax between them. Measure the distance between the concave lens and the second needle Q. It will give the focal length of the concave lens.

The rays of light proceeding from the first needle P retrace their path, to form an image by the side of the object. So, they must fall normally on the plane mirror. Hence, it follows that they are parallel after refraction through the concave lens. Therefore

the position of the second needle Q is the principal focus of the concave lens.

(c) **Using an auxiliary Concave mirror :**

Mount a concave mirror on a stand with its axis horizontal.

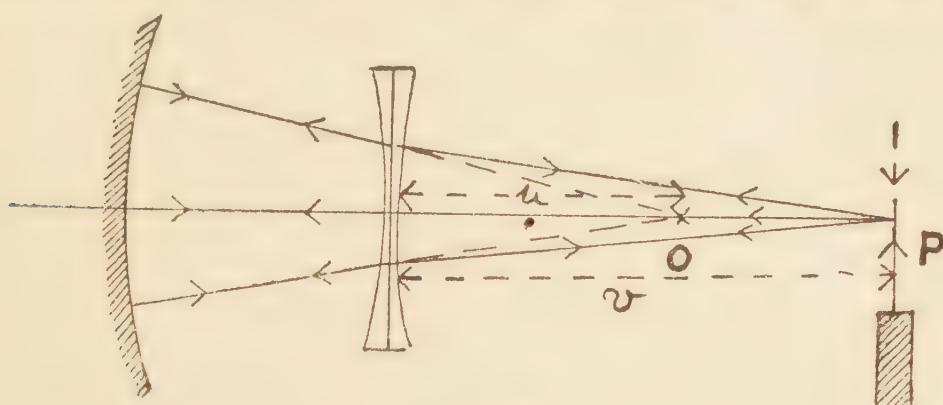


Fig. 109

Place one of the needles in front of it, beyond its principal focus, with its tip on the principal axis. Look towards the mirror and observe the real, inverted image of the needle. Adjust the needle, so that its tip coincides with the tip of the image, without parallax. Measure d_1 , the distance between the centre of the concave mirror and the needle. It is the radius of curvature of the mirror.

Interpose the concave lens between the needle and the concave mirror. The convergent beam falling on the concave lens becomes less convergent. So, the position of the image gets shifted away from the mirror. Adjust the needle, so that its tip again coincides with the tip of the image without parallax. [It is essential that the position of the concave lens should be such that the convergent beam of light passing through it emerges as a convergent beam. Otherwise, no real image is possible.]

Measure d_2 , the distance between the needle and the concave mirror and d , the distance between the concave mirror and the concave lens, measured along their principal axes. Now,

$$u = d_1 - d$$

$$\text{and } v = d_2 - d.$$

u is *negative*, as it represents the distance of the *virtual* object. Calculate f from the formula,

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

Change the position of the concave lens and repeat the experiment. Take six readings.

Tabulate the results as follows :—

Distance between concave mirror and first image d_1	Distance between concave mirror and second image d_2	Distance between concave mirror and concave lens d	$d_1 - d = u$	$d - d_2 = v$	$\frac{1}{u}$	$\frac{1}{v}$	$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$	Focal length f
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$\therefore$ Mean focal length = cms.

EXPERIMENT 54

REFRACTIVE INDICES OF CONVEX AND CONCAVE LENSES

Aim :—To determine the refractive index of the material of (1) a convex lens and (2) a concave lens.

Apparatus required :—Convex lens, concave lens, mounted needles.

(A) Convex lens

Procedure :—The formula for a spherical lens is,

$$\frac{1}{f} = (\mu - 1) \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

where f is its focal length, R_1 and R_2 , the radii of curvature of the surfaces of the lens and μ , its refractive index.

(a) To determine the focal length f :—

Determine the focal length of the convex lens, using one of the mounted needles as the object and locating its image with a second needle, by the method of parallax. Use both the $u-v$ and the displacement methods. Find the mean focal length.

Tabulate the results as follows :—

(i) $u - v$ method

u	v	$\frac{1}{u}$	$\frac{1}{v}$	$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$	Focal length f
-----	-----	---------------	---------------	---	------------------

Mean focal length = cms.

(ii) Displacement method.

Distance between needles l	Distance of lens from one of the needles		$d_1 - d_2 = d$	$\frac{l^2 - d^2}{4l} = f$
	in position I d_1	in position II d_2		

$\therefore$ Mean focal length = cms.

(b) To determine the radii of curvature of the surfaces of the lens—Boys' method

Mount the convex lens on a lens-stand with its axis horizontal. Cover up one of the surfaces with a black paper. Place the needle P, in front of the other surface, with its tip on the principal axis of the lens. Look towards the lens from that side. Illuminate the tip of the needle with bright electric light. The light must be shaded, so as not to fall on the eye or on the surface of the lens.

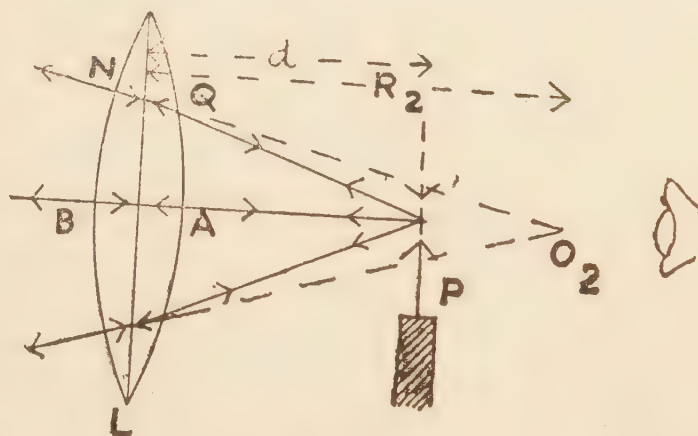


Fig. 110

Place the needle close to the lens and move it away from it, till a real, inverted image of the needle is seen. It is formed by the rays passing through the lens and partly getting reflected from the second surface. Adjust the needle, so that it coincides with its own image without parallax, as the eye is moved from side to side. For this to happen, the rays must fall normally on the second face of the lens and retrace their path. Measure the distance d between the centre of the lens and the needle along the principal axis. Let f be the focal length of the lens. For image formation by the lens,

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

It is obvious that, for the above position, the refracted, *virtual* image of the needle is formed at the centre of curvature O_2 of the second

surface. Let R_2 be its radius of curvature. $R_2 = v$. Since the image is *virtual*, v is *negative*. $u = d$. So,

$$\begin{aligned} \frac{1}{-R_2} + \frac{1}{d} &= \frac{1}{f} \\ \therefore \frac{1}{R_2} &= \frac{1}{d} - \frac{1}{f} \\ \therefore R_2 &= \frac{f d}{(f - d)} \end{aligned}$$

Calculate R_2 .

Do likewise for the other surface and determine R_1 its radius of curvature.

Tabulate the results as follows :—

(1) Radius of curvature R_2 of second surface

f	d_1 by Boys' method	$R_2 = \frac{f d_1}{(f - d_1)}$
-----	-----------------------------	---------------------------------

$\therefore$ Mean $R_2 =$ cms.

(2) Radius of curvature R_1 of first surface

f	d_2 by Boys' method	$R_1 = \frac{f d_2}{f - d_2}$
-----	-----------------------------	-------------------------------

$\therefore$ Mean $R_1 =$ cms.

Now,

$$\frac{1}{f} = (\mu - 1) \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

f , R_1 and R_2 are known.

$$\therefore \mu = 1 + \frac{R_1 \times R_2}{(R_1 + R_2) \times f}$$

$\therefore$ Refractive index of material of convex lens $\left. \begin{array}{l} \dots \end{array} \right\} =$

(B) Concave lens

Procedure :—(1) To determine the focal length: Select a convex lens of such a focal length that when the two are combined, the combination is convergent.

Place the two lenses in contact and mount the combination on a suitable lens-stand. Determine the focal length F , by the $u-v$ method or the displacement method, using two mounted needles.

Then, determine the focal length f_1 of the convex lens alone, similarly.

Now,

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\therefore \frac{1}{f_2} = \frac{1}{F} - \frac{1}{f_1} = \frac{f_1 - F}{F \times f_1}$$

$$\therefore f_2 = \frac{F \times f_1}{f_1 - F}$$

$\therefore$ Focal length f_2 of the concave lens }
alone . . . } =

(2) To determine the radii of curvature of the surfaces of the lens

Mount the concave lens on a lens-stand with its axis horizontal. Place a mounted needle in front of it, with its tip on the principal axis of the lens.

Move it to and fro till it coincides without parallax, with the tip of its own image formed by reflection at the concave surface of the lens. Measure the distance between the centre

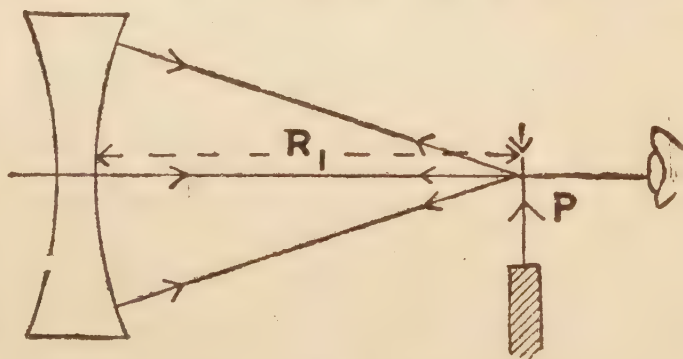


Fig. 111

of the lens and the needle along the principal axis. It is equal to the radius of curvature R_1 of the surface.

Repeat the experiment with the other surface and measure R_2 .

Now,

$$\frac{1}{f} = (\mu - 1) \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

$$\mu = 1 + \frac{(R_1 \times R_2)}{(R_1 + R_2) \times f}$$

$\therefore$ Refractive index of the material of the concave lens =

EXPERIMENT 55

REFRACTIVE INDICES—LIQUID LENS

Aim :—To determine the refractive index of a liquid by forming a liquid lens.

Apparatus required :—Concave mirror, convex lens, a strip of plane mirror, knitting needle, mercury float, liquid.

(A) Concave mirror method

Procedure :—Place the concave mirror flat on the table with its reflecting face upwards and its axis vertical. Clamp a knitting

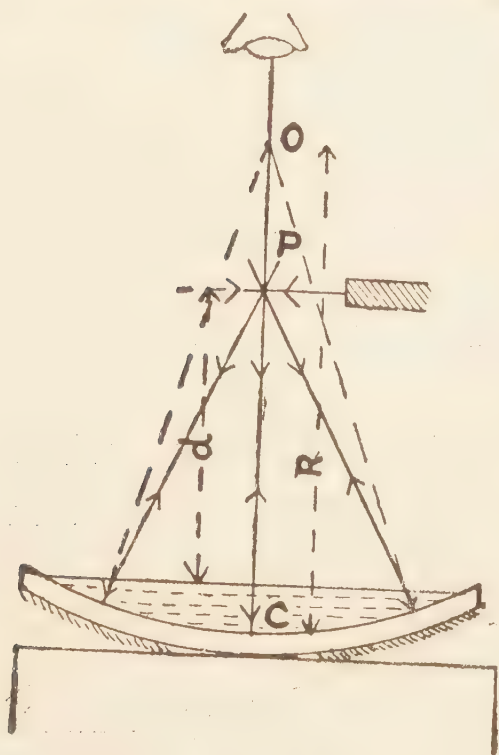


Fig. 112

needle P horizontally. Adjust it, so that its tip lies on the principal axis of the concave mirror. The tip of the needle must be painted white. Keeping the eye above the needle, look towards the mirror. Observe the real, inverted image of the needle. Adjust the needle by raising or lowering it, till its tip coincides with the tip of the image, without parallax, when the eye is moved from side to side. Measure the distance R of the needle from the centre of the mirror along the principal axis.

This is the *radius of curvature* of the mirror.

Pour a small quantity of the liquid on the concave mirror, to a height of 2 to 3 mm. . The liquid will take up the shape of a plano-convex lens, the radius of curvature of the bottom surface being the same as that of the concave mirror.

Look towards the mirror from above the needle. A real, inverted image is formed by the liquid lens and mirror. Adjust the position of the needle, till its tip coincides with the tip of the image without parallax, as the eye is moved from side to side. Measure the distance d from the surface of the liquid to the pin along the principal axis.

The rays of light passing through the liquid lens are incident normally at the surface of the mirror, retrace their path and form

an image by the side of the object. Hence, the virtual image of the needle due to refraction by the liquid lens must be formed at the centre of curvature of the concave mirror. In the formula for a spherical lens,

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

$v = R$, $u = d$. Since the image formed by the liquid lens is *virtual*, v is *negative*. So

$$-\frac{1}{R} + \frac{1}{d} = \frac{1}{f}$$

$$\therefore \frac{1}{f} = \frac{R - d}{Rd}$$

Take two or three readings. Calculate f in each case and find the mean.

Now, f is the focal length of the liquid lens and R , the radius of curvature of one of its faces, the other face being plane. For a lens,

$$\begin{aligned} \frac{1}{f} &= (\mu - 1) \left(\frac{1}{R_1} + \frac{1}{R_2} \right) \\ &= (\mu - 1) \left(\frac{1}{R} + \frac{1}{\infty} \right) \\ &= \frac{\mu - 1}{R} \\ \therefore \mu &= 1 + \frac{R}{f} \end{aligned}$$

Calculate μ , the refractive index of the liquid from the known values of R and f .

(B) Convex lens method

Procedure :—Place the plane mirror strip flat on the table with its reflecting face upwards. Place a double convex lens on the mirror. Its axis must be vertical. Adjust the position of the mounted knitting needle P , so that its tip lies on the principal axis of the lens. Look towards the mirror from above the needle. You will see its real, inverted image. Raise or lower the

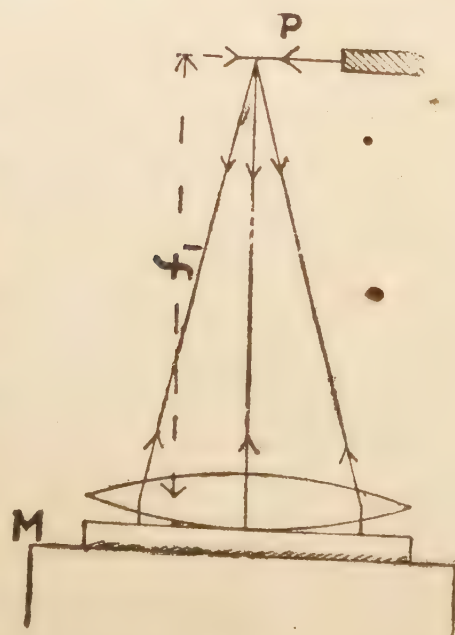


Fig. 113

needle, till its tip coincides with the tip of its image, without parallax, as the eye is moved from side to side. Measure the

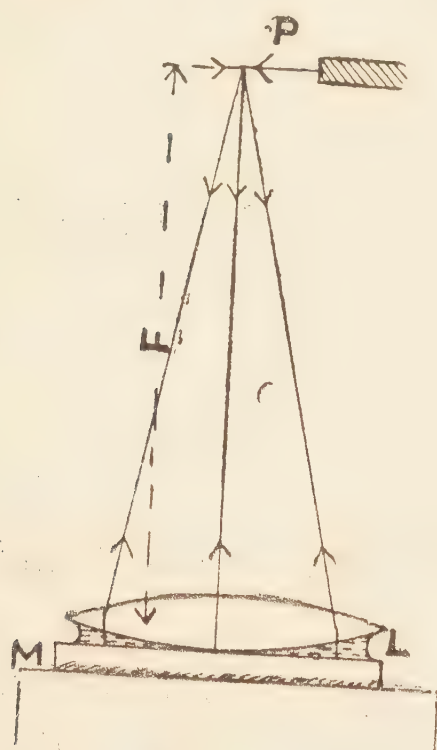


Fig. 114

vertical distances of the needle from the surfaces of the mirror and the lens. Take their average. It will give the *focal length* of the convex lens. Disturb the arrangement and repeat the experiment three or four times. Find the mean value of the focal length. Let it be f_1 .

Introduce a few drops of the liquid between the lens and the mirror. The liquid takes up the shape of a plano-concave lens. So, you have now a combination of a convex lens and a plano-concave lens. Move the needle up and down and adjust it, so that

its tip coincides with the tip of its image, without parallax, when the eye is moved from side to side. Measure the vertical distances of the needle from the surfaces of the plane mirror and the lens and find their average. It will give the focal length of the combination. Disturb the arrangement and repeat the experiment. Take three or four readings. Find the mean focal length F .

Now, for a combination of two thin lenses,

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

From the known values of F the focal length of the combination, f_1 the focal length of the convex lens, calculate f_2 the focal length of the liquid concave lens.

Remove the convex lens and wipe off the liquid from its surface. Float it on a pool of mercury kept in a china dish, with the same surface in contact with the mercury. Adjust the needle, so that its tip is on the axis of the lens. Look from above the needle. Raise or lower it, till its tip coincides with the tip of its own image, without parallax, as the eye is moved from side to side. Measure carefully the vertical distances of the needle from the surfaces of mercury and the lens. Take their average. Let it

be d . Disturb the arrangement and repeat the experiment. Take three or four readings. Find the mean value of d .

Rays from the needle, passing through the lens, fall on its back surface and retrace their path, forming an image by the side of the object. [The mercury surface helps to reflect a large portion of the incident light and to form a bright image of the needle]. Calculate the radius of curvature R_2 of the back surface from the formula,

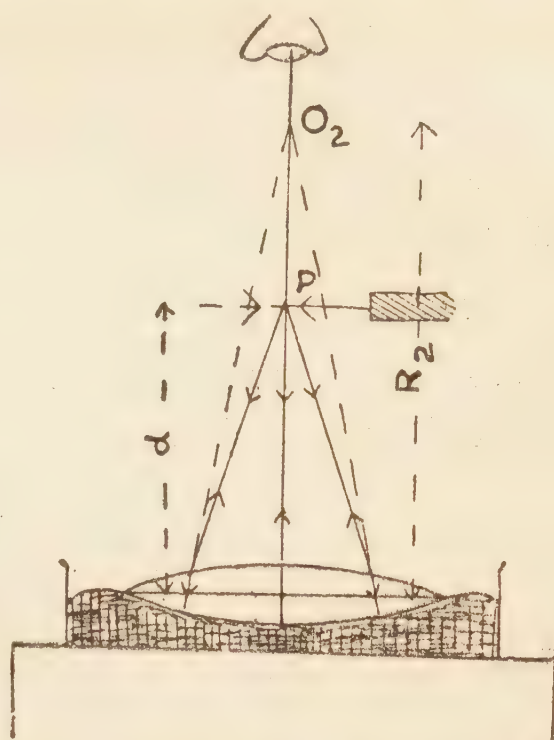


Fig. 115

$$-\frac{1}{R_2} + \frac{1}{d} = \frac{1}{f_1}$$

$$\therefore R_2 = \frac{f_1 d}{f_1 - d}.$$

From the known values of f_1 and d , calculate R_2 .

The formula for the liquid lens is,

$$\frac{1}{f_2} = (\mu - 1) \left(\frac{1}{r_1} + \frac{1}{r_2} \right).$$

where f_2 is its focal length, $r_1 = R_2$ the radius of curvature of its front surface, and $r_2 = \infty$.

$$\therefore \frac{1}{f_2} = (\mu - 1) \frac{1}{R_2}$$

$$\therefore \mu = 1 + \frac{R_2}{f_2}.$$

From the known values of R_2 and f_2 , calculate μ , the refractive index of the lens.

EXPERIMENT 56

MAGNIFYING POWERS OF MICROSCOPES
AND TELESCOPES

Aim :—To determine the magnifying power of (1) a simple microscope (2) a compound microscope and (3) a telescope.

Apparatus required :—Two short focus convex lenses, a long focus convex lens, a vertical scale with large divisions marked on it, half-metre scales.

(A) Simple Microscope

Procedure :—Any convex lens of focal length of about 5 cms. can be used as a simple microscope. Its magnifying power is $\left(1 + \frac{D}{f}\right)$ where f is its focal length and D the least distance of distinct vision (25 cms., for a normal eye).

Find accurately the focal length of one of the short focus convex lenses, using a plane mirror and a mounted knitting needle.

Mount the lens on a stand with its axis horizontal. Fit up two half-metre scales vertically on stands. Place one of the scales P in front of the lens near its principal focus. Place the second scale Q on the same side of the lens at a distance of 25 cms. from the lens.

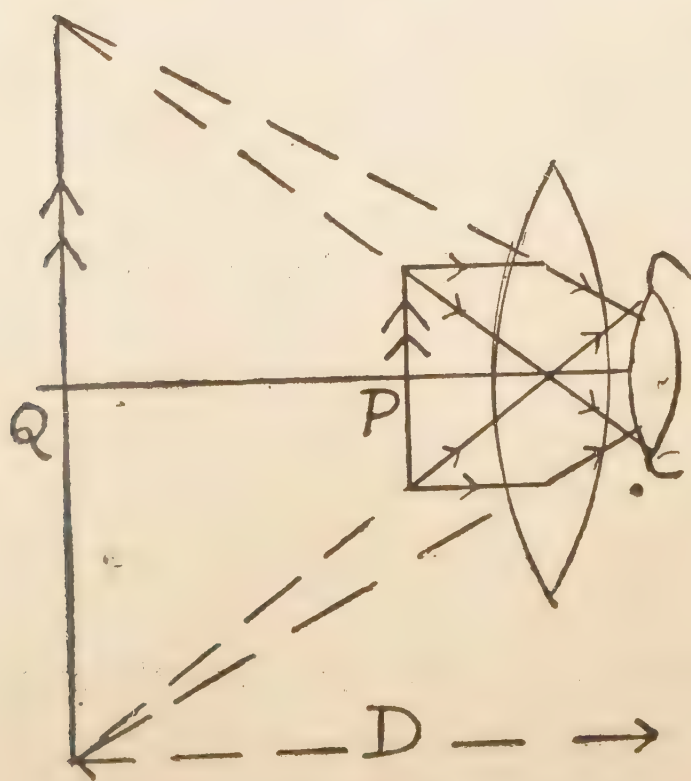


Fig. 116

Keep your eye on the other side, close to the lens. Open both eyes. With one of them, look through the lens at the image of the first scale. With the other, look directly at the other scale. Adjust the distance of the scale near the lens, till the clear magnified image

of the scale divisions on it are superposed on the scale divisions on the second scale seen directly and there is no parallax

between the two. Find the number of divisions N seen directly, which coincide with the number of divisions n seen in the image. Then $\frac{N}{n}$ is the magnifying power. Take two or three readings

Tabulate the results :—

Focal length of convex lens = f cms.

Number of divisions on image of first scale n .	Coinciding number of divisions on second scale N .	$\frac{N}{n}$	$1 + \frac{D}{f}$
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(B) Compound Microscope.

Procedure :—The compound microscope consists of a short focus convex lens, constituting its objective and another similar convex lens, constituting its eye-piece. If an object is placed at a distance of u cms from the objective, the magnification of the microscope is given by the formula,

$$m = \left(\frac{f_1}{u - f_1} \right) \left(1 + \frac{D}{f_2} \right)$$

where f_1 is the focal length of the objective lens and f_2 the focal length of the eye lens.

Find the focal lengths of the two short focus convex lenses using a plane mirror and a mounted knitting needle.

Use the convex lens of the shorter focal length as the objective and the other as the eye-piece. Mount the two lenses on stands with their axes horizontal and at the same height from the table. Place a vertically mounted half-metre scale in front of the objective, just beyond its principal focus. Locate its real image on the other side with a mounted knitting needle. Place the other lens in front of the knitting needle, so that the axes of the two lenses coincide and the knitting needle is just inside the principal focus of the eye-piece. Remove the knitting needle. Place the other mounted scale at a distance of 25 cms. from the eye-piece. Look through the lenses at the image of the first scale with one eye and

directly at the second scale with the other eye. Adjust the eye-piece lens, so that the magnified image of the scale divisions on the first

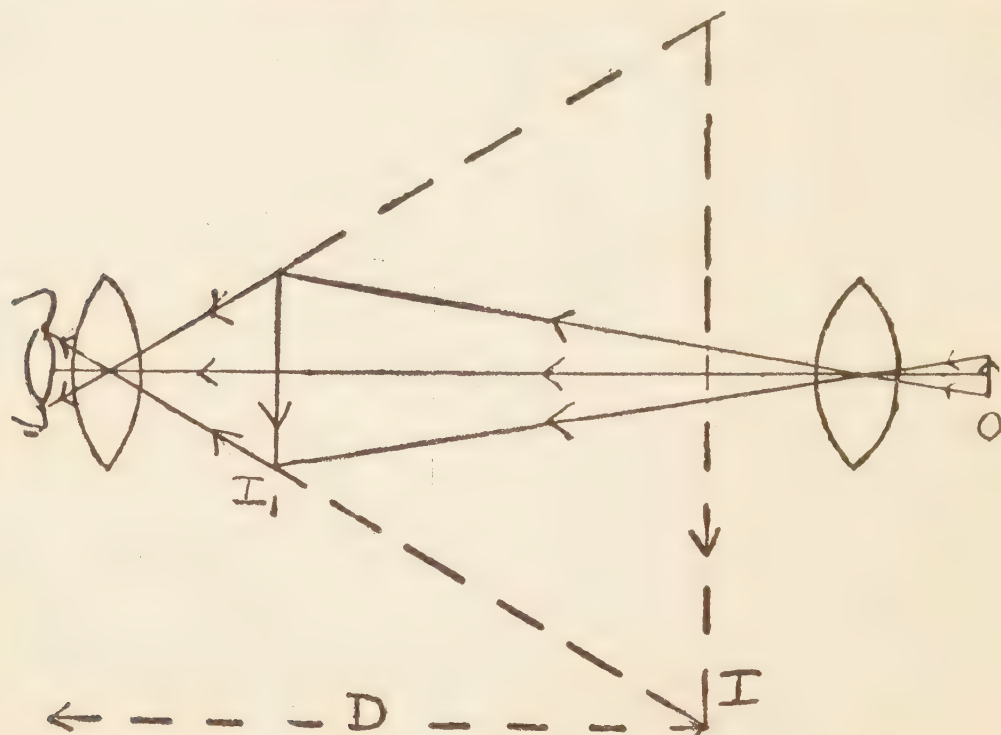


Fig. 117

scale are superposed on the scale divisions on the second scale and there is no parallax between the two.

Find the number of divisions N on the second scale coinciding with n divisions on the first scale. Then, $\frac{N}{n}$ is the magnifying power of the microscope. Take two or three readings.

Tabulate the readings as follows :—

Focal length of the objective = f_1

Focal length of eye-piece = f_2

Distance of first scale from objective u	Number of divisions on first scale n	Coinciding number of divisions on second scale N	$\frac{N}{n}$	$\left(\frac{f_1}{u - f_1} \right) \left(1 + \frac{D}{f_2} \right)$
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(C) Telescope

Procedure :—The Astronomical telescope has for its objective, a convex lens of long focal length and for its eye-piece, a convex lens of short focal length.

The magnifying power of a telescope for an object at infinity is given by $\frac{F}{f}$, where F is the focal length of the objective and f is the focal length of the eye-piece.

If the distance of the object from the objective is D , then a small correction has to be applied. The magnifying power m_D is given by,

$$m_D = \frac{F}{f} \left(1 + \frac{2F}{D} \right)$$

$$= m_\infty \left(1 + \frac{2F}{D} \right)$$

Find the focal lengths of a long focus convex lens and a short focus convex lens, using a plane mirror and a mounted needle.

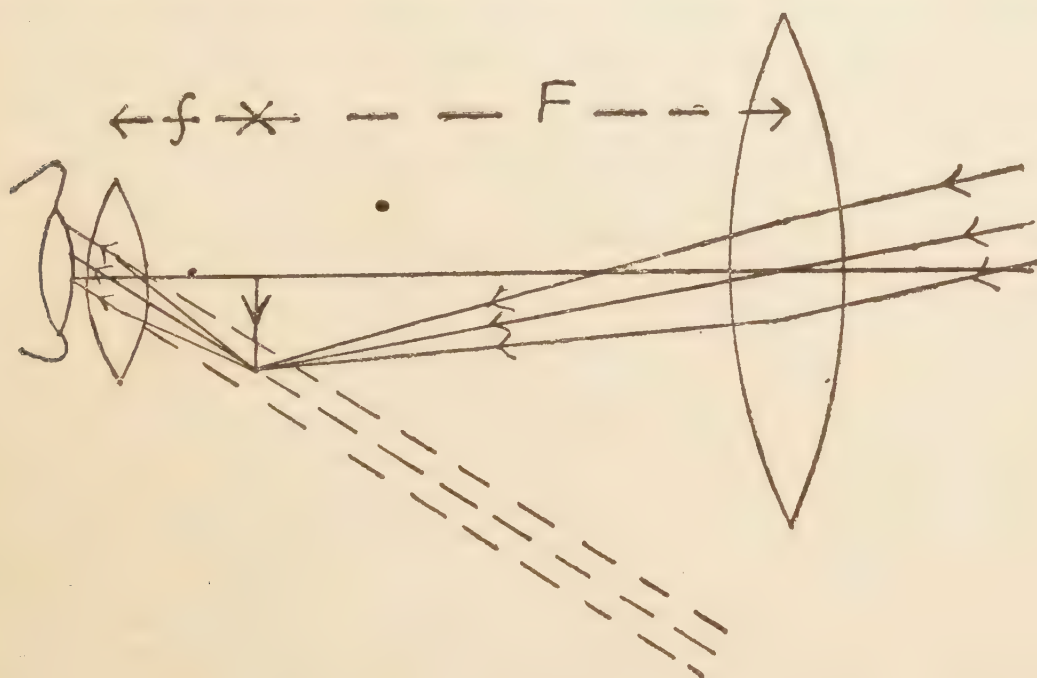


Fig. 118

Mount the two lenses coaxially on lens-stands. Adjust the distance between them so as to be equal to the sum of their focal lengths. The combination constitutes a telescope.

Hang a scale with large equal divisions marked on it, vertically, on a distant wall. Turn the telescope towards the wall. Look at the image of the scale seen in the telescope with one eye and at the scale directly, with the other eye. The divisions on the scale should be large enough to be seen by the eye directly. Adjust the eye-piece so that, the scale divisions seen directly are superposed over the clear image of the scale divisions seen through the telescope, without parallax. Find the number of divisions n on the image, coinciding with the number of divisions N on the scale, seen directly. Then $\frac{N}{n}$ will be the magnifying power of the teles-

cope. Take two or three readings. Measure the distance D between the objective and the scale. Alter the distance and repeat the experiment. Take six readings.

Tabulate the results as follows :—

Focal length of objective

Focal length of eye-piece

∴ Magnifying power for infinity

distance m_{∞}

=

=

}

=

=

32.4 cms.

4.2 cms.

$\frac{32.4}{4.2}$

7.7

Distance of scale D	Number of divisions on scale N	Coinciding number of divisions on image n	Magnifying power m_D	$m_{\infty} = \frac{m_D}{1 + \frac{2F}{D}}$
825 cms.	16.5	2	8.3	7.7
625 „	17.0	2	8.5	7.7
425 „	9.0	1	9.0	7.8
225 „	10.0	1	10.0	7.8
Mean				7.8

(D) Focal length of eye-piece

The eye-pieces used in telescopes are made up of two convex lenses placed at a distance from each other. The combination functions as the eye-piece. It is not possible to determine its focal length directly. So, the following method is used for determining its focal length.

Determine the magnifying power of a telescope experimentally. Keep a vertical scale at measured distances from the telescope, and by the method indicated above, find the magnifying power for each distance.

Screw out the objective lens and find its focal length using a plane mirror and mounted needle.

Now, $m_D = \frac{F}{f} \left(1 + \frac{2F}{D} \right)$

∴ $\frac{F}{f} = \frac{m_D}{1 + \frac{2F}{D}}$

From the average value of $\frac{F}{f}$, and the known value of F , f can be calculated.

Tabulate the readings as follows :—

Focal length of objective lens = 15.2 cms.

Distance of scale D	Magnifying power m_D	$\frac{m_D}{1 + \frac{2F}{D}} = \frac{F}{f}$
400 cms.	7.4	6.88
600 „	7.2	6.86
800 „	7.1	6.84
1000 „	7.0	6.86
Mean		6.86

$$\therefore \text{Mean value of } \frac{F}{f} = 6.86$$

$$\therefore \left. \begin{array}{l} \text{The focal length} \\ \text{f of eye-piece} \end{array} \right\} = \frac{15.2}{6.86} = 2.2 \text{ cms.}$$

Alternative method :—

Adjust the eye-piece of the telescope so that the cross-wires are distinctly seen. Turn the telescope towards a distant object and adjust it, so that a clear image of the distant object is formed on the cross-wires. Without disturbing the adjustment, screw out the objective. Substitute in its place a disc with a circular hole.

Turn the telescope towards a white wall with its axis horizontal. Find the least count of a vernier microscope. Place it in front of the eye-piece. Turn it, so that its axis is horizontal and passes through the centre of the eye-piece. Move the microscope to and fro and focus it on the image of the circular hole formed by the eye-piece. Measure the diameter of the image of the circular hole. Let it be d_2 .

Measure directly the diameter of the circular hole with the microscope. Let it be d_1 . Then,

$$\frac{d_1}{d_2} = \frac{F}{f} \quad \therefore f = \frac{F \times d_2}{d_1}$$

Tabulate the readings as follows :—

Diameter of circular hole	= 1.39 cms.
Diameter of its image	= 0.21 „
Focal length of objective	= 15.2 „

$$\therefore f = \frac{15.2 \times 0.21}{1.39} = 2.2 \text{ cms.}$$

$\therefore$ The focal length of the eye piece = 2.2. cms.

Note :—

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

$$\therefore \frac{u}{v} = \frac{u}{f} - 1 = \frac{F + f}{f} - 1 = \frac{F}{f}$$

$$\therefore \frac{d_1}{d_2} = \frac{u}{v} = \frac{F}{f}$$

EXPERIMENT 57

RESOLVING POWER OF A TELESCOPE

Aim :—To determine the resolving power of a telescope experimentally.

Apparatus required :—Telescope, an adjustable rectangular slit, a wire-gauze with uniform meshes, sodium light.

Procedure :—Mount the wire-gauge vertically in front of a sodium flame. Set up the telescope at a distance of 2 or 3 metres from the illuminated wire-gauge, Adjust the telescope, so that the vertical and horizontal wires of the wire-gauze are seen clearly. Fit up the adjustable rectangular slit to a clamp with its edge vertical and place it close to the objective of the telescope.

Looking through the telescope, adjust the width of the slit so that the vertical wires just disappear. Remove the slit and measure its width accurately with a vernier microscope. Measure also the distance between the wire-gauze and the telescope.

Increase the distance between the telescope and the wire-gauze by 100 cms. Adjust the width of the slit so that the vertical wires just disappear. Measure the width of the slit and the distance between the telescope and the wire-gauze.

Repeat the experiment, increasing the distance between the telescope and the wire-gauze by 100 cms. at a time. In each case, determine the width of the slit for which the vertical wires just disappear. Take six readings.

Remove the wire-gauze. Measure with a vernier microscope, the length of, say, 10 meshes on the wire-gauge. Hence, calculate the distance between two adjacent wires.

Theory :—Let d be the mean distance between two adjacent wires, D the distance between the wire-gauze and the telescope, a the width of the slit AB , when the vertical wires just disappear and λ , the wave length of sodium light.

Each source of light produces its own diffraction pattern at the focal plane of the objective. It consists of a bright central

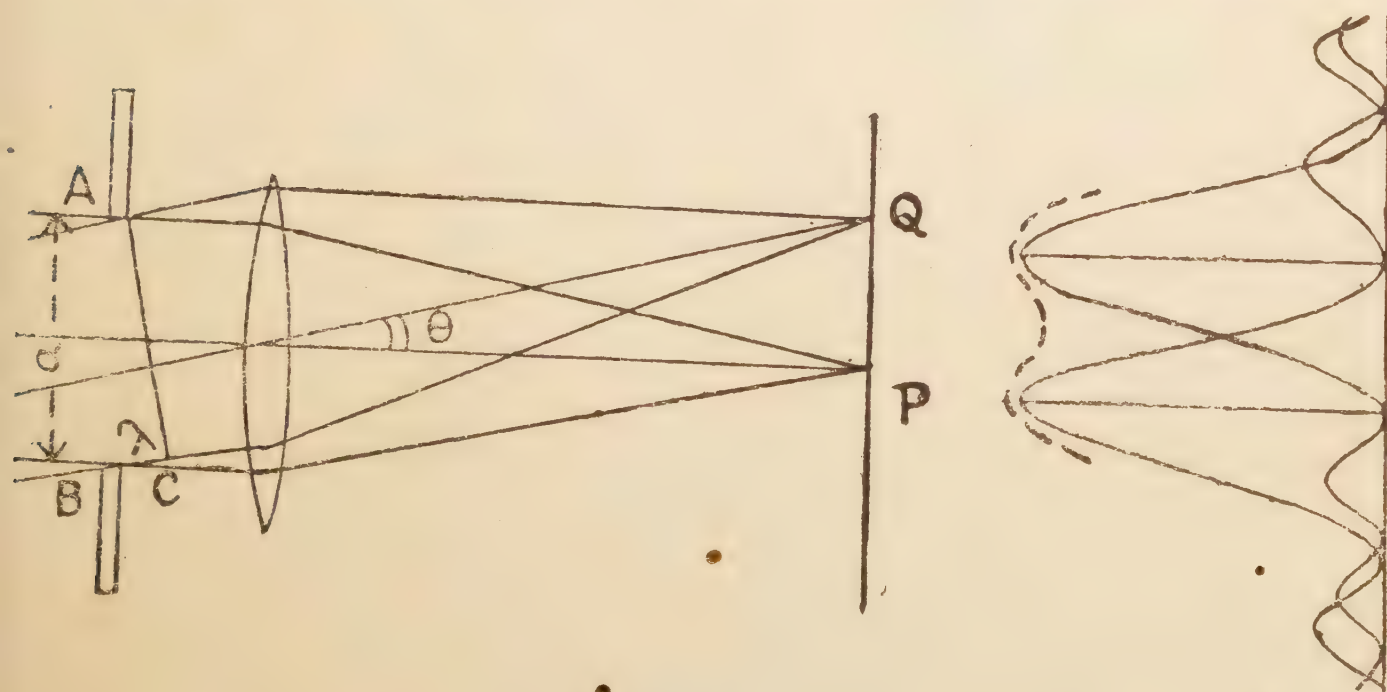


Fig. 119

maximum, with subsidiary maxima and minima on either side of it. Two sources of light, close together, appear just separated, if the central maximum due to one of them falls on the first minimum due to the other (See fig.). The angular separation θ between the two is $\frac{\lambda}{a}$, where λ is the wave-length of the source of light and a the width of the aperture.

The angular separation θ of the two sources of light is $\frac{d}{D}$ where d is the distance between the two sources and D is the distance between the sources and the objective.

So, when the two sources just appear separate,

$$\theta = \frac{\lambda}{a} = \frac{d}{D}.$$

$\frac{\lambda}{a}$ is known as *the limit of resolution* and $\frac{a}{\lambda}$, the *resolving power* of the objective.

Tabulate the results as follows :—

Mean width of a mesh in the } = 0.128 cms.
wire-gauze (d).

Wave-length of Sodium light. = 5893×10^{-8} cms,

Distance between wire-guage and objective D	Width of aperture a	$\frac{d}{D}$ $\times 10^4$	$\frac{\lambda}{a}$ $\times 10^4$
100 cms.	0.048 cms.	12.8	12.3
200 „	0.096 „	6.4	6.2
400 „	0.182 „	3.2	3.2
700 „	0.324 „	1.8	1.8

EXPERIMENT 58

SPECTROMETER

ANGLE OF PRISM-MINIMUM DEVIATION

Aim :—To determine (1) the angle of a prism, and (2) the angle of minimum deviation for the prism, using a spectrometer and to calculate its refractive index.

Apparatus required :—Spectrometer, equilateral glass prism, spirit level and sodium light.

Description of apparatus :—The Spectrometer essentially consists of (1) a fixed collimator, (2) a telescope, (3) a horizontal circular scale and (4) a prism-table with a circular disc carrying two verniers, attached to it.

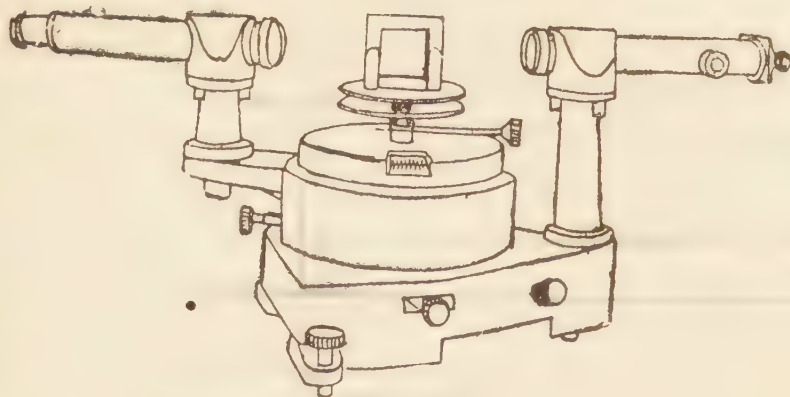


Fig. 120

The **collimator** has a convex lens fitted at its inner end and an adjustable rectangular slit, at its outer end. When the slit is illuminated and adjusted to be at the principal focus of the convex lens, a parallel beam of light emerges from the collimator. It is mounted on a fixed bracket, with its axis horizontal and pointing to the centre of the instrument. The slit and the convex lens are fitted to two different cylindrical tubes sliding into one another. A rack and pinion arrangement is usually provided for adjusting the distance between the slit and the convex lens.

The **telescope** is an astronomical telescope, with rack and pinion arrangement for focussing. The eye-piece is fitted with cross-wires. It is mounted on a bracket, with its axis horizontal and pointing towards the centre of the instrument. The telescope can be rotated about a vertical axis passing through the centre of the circular scale.

The **circular scale**, divided into degrees and half-degrees, is at the centre of the instrument. It is attached to the telescope arm, so that when the telescope rotates, the scale rotates along with it.

The **prism-table**, with a circular disc carrying the verniers, is mounted coaxially with the circular scale. They rotate about the same vertical axis. When the prism-table is rotated, the verniers move over the circular scale. The relative angular displacement between the telescope and the prism-table can be found out from the scale and the vernier readings. The verniers are on opposite sides of the centre of the disc.

The prism-table has two circular platforms, a lower one which is fixed and an upper one resting on three levelling screws fixed to the lower platform. By manipulating the levelling screws, the upper platform can be adjusted to be horizontal. It is intended for placing prisms and gratings. Its top surface is marked with parallel lines, parallel to the line joining two of the levelling screws.

The telescope and the prism-table are provided with radial screws for being fixed in any position and tangential screws for giving small movements.

Adjustments :—The instrument can be used, if (1) the collimator provides a parallel beam of light, (2) the telescope on receiving it forms a clear image on the cross-wires and (3) the prism-table is horizontal.

Hold a white surface in front of the telescope and adjust the eye-piece so that the cross-wires are in clear focus. Look with one eye through the eye-piece and with the other at the white surface. The cross-wires must appear like two clear dark lines drawn on the white surface.

Turn the telescope towards a distant object. Adjust it, so that a clear, well-defined image of the distant object is formed on the cross-wires, without parallax.

Turn the telescope, so that its axis and the axis of the collimator are along the same line. Illuminate the slit of the collimator. Adjust the distance between the slit and the lens in the collimator, so that a clear, well-defined image of the slit is formed on the cross-wires, without parallax. The edges of the slit must be vertical. While taking readings, the point of intersection of the cross-wires is made to coincide with the fixed edge of the image of the slit, without parallax.

Place a spirit-level on the prism-table, parallel to the line joining two of the levelling screws. Adjust one of them, so that the bubble comes to the centre. Place the spirit-level in a perpendicular direction. Adjust the third levelling screw, so that the bubble comes to the centre. If the spirit-level is placed anywhere

on the table now, the bubble must remain at the centre. Hence, the prism-table is horizontal.

[It may happen that, after the prism-table has been levelled, if the position of the spectrometer is shifted, the levelling gets altered. So, it has to be done over again.]

(A) ANGLE OF THE PRISM

Procedure :—In the prisms used for spectroscopic work, two of the refracting faces are optically plane and polished. The third face and the two sides are ground. Do not touch the polished faces with the hands. Lift the prism with the fingers pressing the ground sides.

Examine the circular scale and the verniers. Find the value of each scale division and each vernier division and calculate the least count.

(1) **Keeping the prism-table fixed :—**Place the prism on the prism-table with its refracting edge at the centre of the table. Fix it with the prism clamp with the ground face close to it. Rotate the prism-table so that the edge of the prism faces the collimator. Fix the prism-table. Illuminate the slit of the collimator with sodium light. [For this part of the experiment, you may use white light.] The parallel beam of light emerging from the collimator falls on the polished faces, on both sides of the refracting edge. Both the faces reflect the light falling on them.

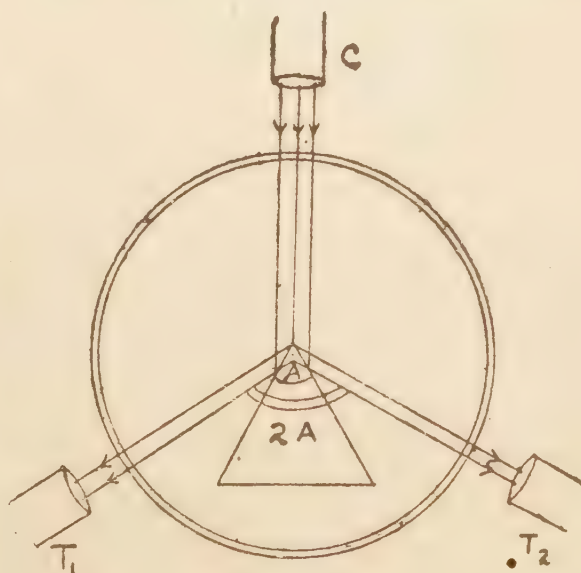


Fig. 121

Turn the telescope to receive the beam reflected from one of the faces. If you are not performing the experiment in a dark room, cover the collimator, telescope and the prism-table with a black cloth. It will cut off extraneous light, from falling on the faces of the prism. Fix the telescope and adjust the tangential screw till the point of intersection of the cross-wires coincides with the fixed edge of the slit, without parallax. [Do not keep

the slit very narrow. It may be difficult to locate the image, if it is very narrow.] Read the circular scale and add to it the vernier reading, obtained by multiplying the coinciding vernier reading by the least count. Read both the verniers.

Release the telescope. Turn it so as to receive the reflected beam from the other face. As before, make the point of intersection of the cross-wires coincide with the fixed edge of the image of the slit, without parallax. Read the scale and the verniers. Alter the position of the prism and repeat the experiment. Take two or three readings.

The angle between the two reflected beams is twice the angle of the prism. So, half the angle through which the telescope is rotated, gives the angle of the prism.

Tabulate the readings as follows :—

$$\begin{aligned}
 \text{One main scale division} &= \frac{1^\circ}{2} \\
 \text{One vernier scale division} &= \frac{29^\circ}{60} \\
 \therefore \text{Least count of vernier} &= \frac{1^\circ}{60} \\
 &= 1 \text{ minute}
 \end{aligned}$$

Trial No.	Reading of reflected ray				Difference in reading	
	Left		Right			
	Vernier A	Vernier B	Vernier A	Vernier B	Vernier A	Vernier B
1	267°51'	87°52'	147°55'	327°57'	119°56'	119°55'
2	333°20'	153°21'	213°23'	33°25'	119°57'	119°56'
3	108°41'	288°38'	348°46'	168°43'	119°55'	119°55'
Mean					119°56'	119°55'

$$\begin{aligned}
 \therefore \text{Mean angle of the prism} &= \frac{119^\circ 55' 30''}{2} \\
 &= 59^\circ 58'.
 \end{aligned}$$

(2) **Keeping the telescope fixed :—**After setting up the prism as in the previous experiment, rotate the telescope, so that the reflected image from one of the faces is seen in the field of the view. Fix the telescope and with the tangent screw, make the point of intersection of the cross-wire coincide with the fixed edge of the slit, without parallax. Read the scale and the verniers.

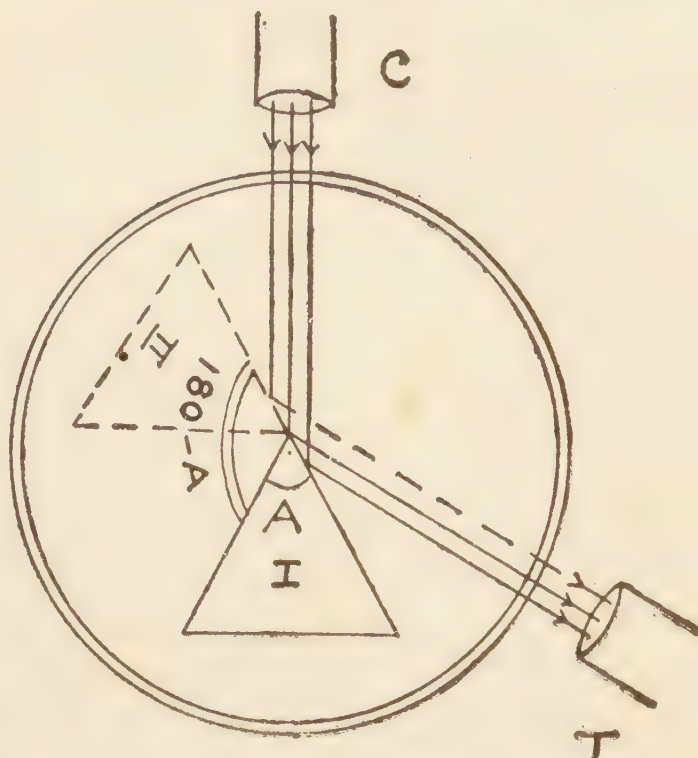


Fig. I22

Release the prism-table and rotate it, so that the reflected image

from the other face is now seen in the field of view of the telescope. Fix the prism-table. Work the tangent screw attached to the prism-table, till the point of intersection of the cross-wires coincides with the fixed edge of the slit. Read the scale and the verniers.

From the readings, find the angle through which the telescope is rotated. Subtract it from 180° . The value obtained is equal to the angle of the prism. Alter the position of the prism and repeat the experiment. Take two or three readings.

Tabulate the readings as follows :—

Least count of the vernier = $1'$

Trial No.	Reading of Prism-table				Difference in reading	
	Position I		Position II			
	Vernier A	Vernier B	Vernier A	Vernier B	Vernier A	Vernier B
1	348°46'	168°43'	228°42'	48°41'	120°4'	120°2'
2	281°2'	101°1'	41°7'	221°5'	120°5'	120°4'
3	232°21'	52°22'	112°17'	292°17'	120°4'	120°5'
Mean					120°4'	120°4'

$$\begin{array}{rcl}
 \therefore \text{Mean angle of the prism} & = & 180^\circ \\
 & & - 120^\circ 4' \\
 \hline
 & & 59^\circ 56'
 \end{array}$$

$$\therefore \text{Mean value of angle of the prism} \} = 59^\circ 57'$$

(B) ANGLE OF MINIMUM DEVIATION

Procedure:—Illuminate the slit with sodium light. Place the prism on the prism-table with its centre at the centre of the table. Fix it with the clamp. Turn the prism-table, so that one of the polished faces receives the light obliquely from the collimator. The base of the prism must be nearer the collimator than the edge. Only then, the beam of light will *emerge* from the prism after refraction. Turn the telescope so that the refracted image of the slit is seen in the field of view. Rotate the prism-table slightly. Find out in which direction the image moves — towards the axis of the collimator or away from it. Rotate the prism-table in such a direction that the image moves towards the axis of the collimator. This means that the angle of deviation is decreasing. Move the telescope to keep the image in the field of view. Rotate the prism-table, till the image ceases to move towards the axis of the collimator and retraces its path. Adjust the position of the prism-table, so that the image is nearest the axis of the collimator. This is the position of minimum deviation for the prism. Adjust the position of the telescope, so that the point of inter-section of the cross-wires coincides with the fixed edge of the slit. Make sure that any slight rotation of the prism-table in either direction results in the image moving only in one direction i.e., away from the axis of the collimator. Fix the prism-table. Read the scale and the verniers.

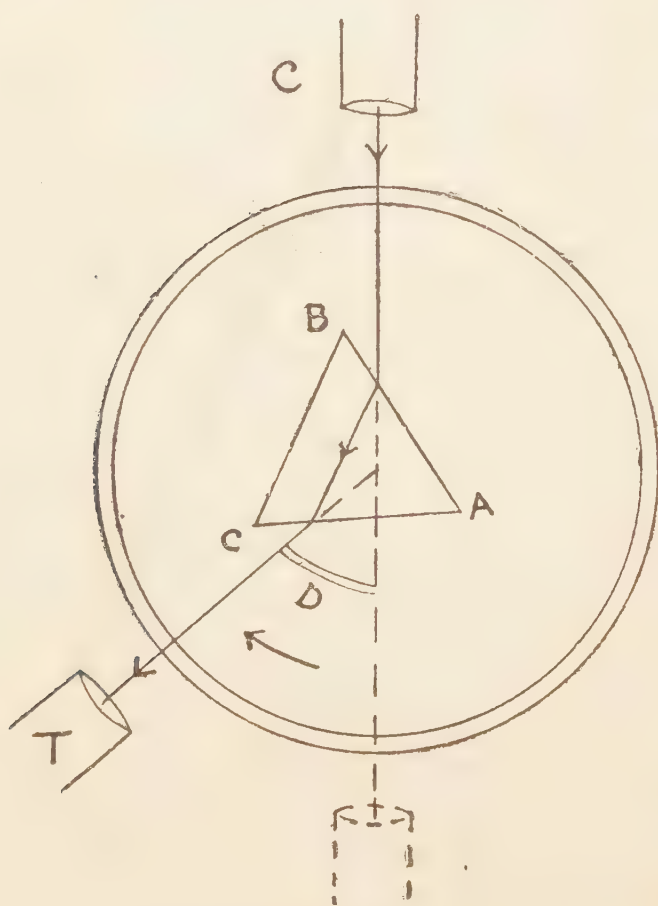


Fig. 123

the telescope to keep the image in the field of view. Rotate the prism-table, till the image ceases to move towards the axis of the collimator and retraces its path. Adjust the position of the prism-table, so that the image is nearest the axis of the collimator. This is the position of minimum deviation for the prism. Adjust the position of the telescope, so that the point of inter-section of the cross-wires coincides with the fixed edge of the slit. Make sure that any slight rotation of the prism-table in either direction results in the image moving only in one direction i.e., away from the axis of the collimator. Fix the prism-table. Read the scale and the verniers.

Remove the prism without disturbing the prism-table, rotate the telescope, so that its axis and that of the collimator are

along the same line. Make the point of inter-section of the cross-wires coincide with the fixed edge of the slit. Take the reading. It is the direct reading. The difference between this reading and the previous one gives the *angle of minimum deviation* for the prism.

Replace the prism, such that the beam of light will be deviated in the opposite direction. Receive the emergent beam in the telescope and as described already, adjust the prism-table for the position of minimum deviation. Move the telescope and adjust its position so that the point of inter-section of the cross-wires coincides with the fixed edge of the slit. Read the scale and vernier. Remove the prism and take the direct reading. The difference between the two readings gives the angle of minimum deviation.

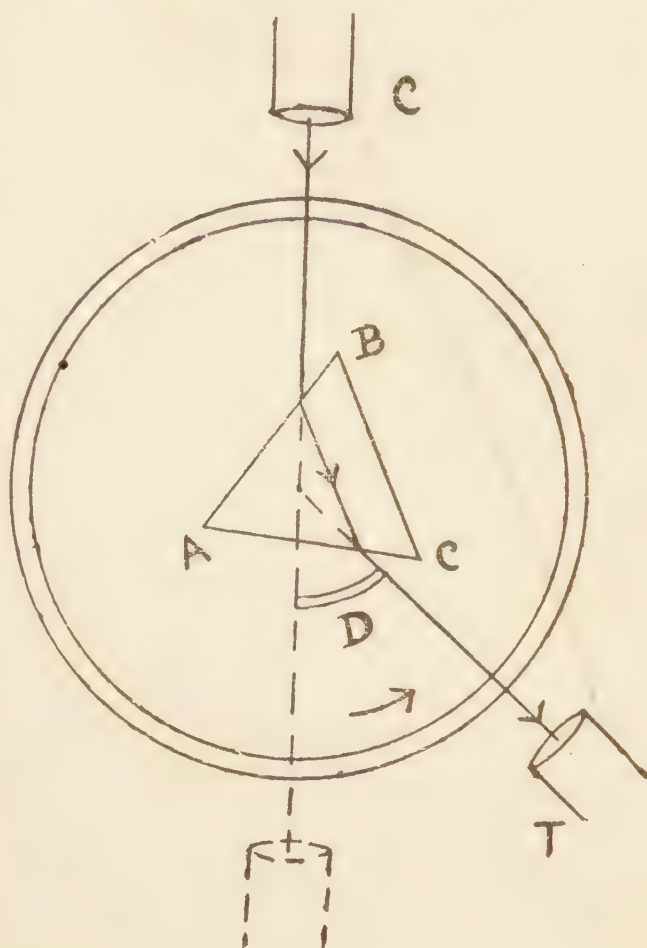


Fig. 124

Tabulate the results as follows :—

Trial No.	Position I.		Angle of minimum deviation.	Position II.		Angle of minimum deviation..
	Reading of refracted ray.	Direct Reading.		Reading of refracted ray.	Direct Reading	
(1)						
Vernier A ...	253°20'	292°0'	38°40'	330°3'	291°22'	38°41'
Vernier B ...	73°20'	111°59'	38°39'	150°1'	111°22'	38°39'
(2)						
Vernier A ...	209°8'	247°51'	38°43'	288°40'	249°58'	38°42'
Vernier B ...	29°9'	67°52'	38°43'	108°41'	69°59'	38°42'
(3)						
Vernier A ...	162°34'	201°15'	38°41'	241°10'	202°28'	38°42'
Vernier B ...	342°33'	21°17'	38°44'	61°10'	22°30'	38°40'

∴ Mean angle of minimum deviation = 38°41'

(C) REFRACTIVE INDEX OF THE PRISM

$$\text{Refractive index of a prism } \mu = \frac{\sin \frac{(D + A)}{2}}{\sin \frac{A}{2}}$$

where D is the angle of minimum deviation of the prism and A, the angle of the prism.

Substituting,

$$\begin{aligned} \mu &= \frac{\sin \frac{(38^\circ 41' + 59^\circ 57')}{2}}{\sin \frac{59^\circ 57'}{2}} \\ &= \frac{\sin 49^\circ 19'}{\sin 29^\circ 59'} = 1.518 \end{aligned}$$

$\therefore$ The refractive index of the prism for sodium light } = 1.518

EXPERIMENT 59

SPECTROMETER

REFRACTIVE INDEX OF LIQUID—HOLLOW PRISM

Aim :—To determine the refractive index of a liquid using a hollow prism by the minimum deviation method.

Apparatus required :—Spectrometer, hollow prism, liquid.

Procedure :—Adjust the eye-piece so that the cross-wires are seen clearly. Turn the telescope towards a distant object and adjust it for parallel rays. Place the telescope in a line with the collimator. Adjust the collimator, so that a well-defined image of the slit is seen in the telescope coinciding with the cross-wires, without parallax. Using a spirit-level, adjust the prism-table so that it is horizontal. Find the least count of the vernier.

(1) **Angle of prism :—**Fill the hollow prism with the liquid. Wipe the outside clean. Place it on the prism-table, with one of the edges, at the centre of the table, facing the collimator. Clamp the prism-table. Illuminate the slit with sodium light.

The beam of light emerging from the collimator falls on the two faces of the prism, on both sides of the edge. Rotate the telescope to receive the light reflected from one of the faces. Adjust its position, so that the point of intersection of the cross-wires coincides with the fixed edge of the slit. Read the scale and the verniers. Note down the reading.

Rotate the telescope so as to receive the light reflected from the other face. Adjust its position so that the intersection of the cross-wires coincides with the fixed edge of the slit. Read the scale and the verniers and note down the reading.

The difference between the two readings gives twice the angle of the prism. Alter the position of the prism and repeat the experiment. Take two or three readings. Carefully mark the edge used.

(2) **Angle of minimum deviation** :—Set the prism on the prism-table with its centre at the centre of the table and with one of its faces receiving the incident beam of light from the collimator, obliquely. Look for the refracted image and move the telescope to receive it. Adjust the prism-table and telescope for the position of minimum deviation of the prism. Fix the prism-table. Make the point of intersection of the cross-wires coincide with the fixed edge of the slit. Read the scale and the verniers and note down the reading.

Remove the prism without disturbing the prism-table, and rotate the telescope, so as to be in a line with the collimator. Adjust it, so that the point of intersection of the cross-wires coincides with the fixed edge of the slit. Take the reading.

The difference between the two readings gives the angle of minimum deviation.

Place the prism on the prism-table, with the other refracting surface of the prism facing the collimator. Turn the telescope to receive the refracted beam. Adjust the prism-table and the telescope for the position of minimum deviation. Fix the prism-table. Make the point of intersection of the cross-wires coincide with the fixed edge of the slit. Take the reading.

Remove the prism. Take the direct reading. The difference between the two readings gives the angle of minimum deviation.

Repeat the experiment and take two or three readings.

Tabulate the readings as follows :—

Liquid used — ; Temperature of liquid = °C

(1) Angle of prism

Least count of vernier =

Trial No.	Reading of reflected ray				Difference in reading	
	Left		Right			
	Vernier A	Vernier B	Vernier A	Vernier B		
1						
2						
3						

∴ Mean angle of the prism =

(2) Angle of minimum deviation

Trial No.	Ver-nier.	Position I.			Position II.		
		Reading of refracted ray.	Direct read-ing.	Angle of mini-mum deviation	Reading of refracted ray.	Direct read-ing.	Angle of mini-mum devia-tion.
1	A						
2	B						

∴ Mean angle of minimum deviation =

(3) Refractive index :—

$$\mu = \frac{\sin \frac{(D + A)}{2}}{\sin \frac{A}{2}}$$

Substitute the values of D and A and calculate μ .

$\therefore$ The refractive index of the liquid for sodium }
light at $^{\circ}\text{C}$... } =

Note :—The glass plates forming the faces of the prism may not have optically plane and parallel surfaces. If they are detachable, they must be rotated through 180° . The edges of the plates nearest the refracting angle must be turned, so as to be nearest the base and the experiment repeated. Again while measuring the angle of the prism, you will see two images. The brighter one is due to reflection at the first surface. Use this image.

EXPERIMENT 60

SPECTROMETER

(I — D) CURVE

Aim :—To measure the angle of deviation for a prism for various angles of incidence, with the spectrometer and draw the (i — d) curve.

Apparatus required :—Spectrometer, sodium light, equilateral glass prism.

Procedure :—Adjust the spectrometer for use. Besides the usual method for adjusting the spectrometer, described in experiment 58, there is another *optical* method. You may learn the method. It is known as Schuster's method.

Adjust the eye-piece of the telescope, so that the cross-wires are seen distinctly.

Illuminate the collimator slit with sodium light. Place the prism on the prism-table, round about the position of minimum deviation. Turn the telescope so that the refracted image of the slit is seen in the field of view. Fix the telescope. If the prism-table is rotated, the image will move across the field of view. Find out in which direction the prism-table has to be rotated, for the

image to move towards the position of minimum deviation and retrace its path. You will find, that there are two positions of the prism-table, for which the image will be in the field of view of the telescope. In one of the positions, the incident beam will make a larger angle of incidence with the face of the prism than in the other.

Suppose the image is not in clear focus. Then, in the more slanting position of the face of the prism, adjust the telescope, till the image is clear. Turn the prism to the less slanting position. Adjust the collimator, so that the image is in clear focus. Turn it back to the other position and adjust the telescope. Repeat the process, till, in both the positions, the image is clearly focussed.

[In practice, it is unnecessary to remember in which position the telescope must be adjusted and in which position, the collimator. Find by trial, by adjusting the telescope in one of the positions and the collimator in the other, whether the focussing improves, as the prism is moved from one position to the other. Otherwise, reverse the order. This method was devised by Schuster. The adjustments can be done even in a dark room.]

Then, level the prism-table. Set the prism, so that the refracting edge faces the collimator and one of the polished faces is perpendicular to the line joining two of the screws. Turn the telescope to receive the reflected image from this face. If the image of the slit is not in the centre of the field of view, adjust one of the levelling screws and bring the image to the centre. Turn the telescope, to receive the image due to the other face. Adjust the third levelling screw and bring the image to the centre. Turn it to the other position and adjust again the first levelling screw, if necessary, to bring the image to the centre. Repeat the process, till the image is in the centre of the field of view in both the positions.

Get familiar with the above method of adjusting the spectrometer. It will be of great use.

(I — D) CURVE

To draw the (i — d) curve, you must find the angles of deviation, for various angles of incidence. Place the

telescope in a line with the collimator. Adjust its position so that the point of inter-section of the cross-wires coincides with the fixed edge of the slit. Fix the prism-table. Take the reading. If this reading is adjusted to be 0° or 180° , it will be convenient. This is the direct reading. If the prism-table is not disturbed, this reading will be the same, whenever the telescope and the collimator are in a line. Read both the verniers.

From the direct reading, subtract $(180 - 2i)$, where i is the required angle of incidence. Rotate the telescope and fix it in the position T_2 corresponding to the above reading. The angle between the axes of the collimator and the telescope will be $2i$. Set the prism on the platform, with one of its faces receiving the incident beam from the collimator and with the centre of the prism coinciding with the centre of the platform.

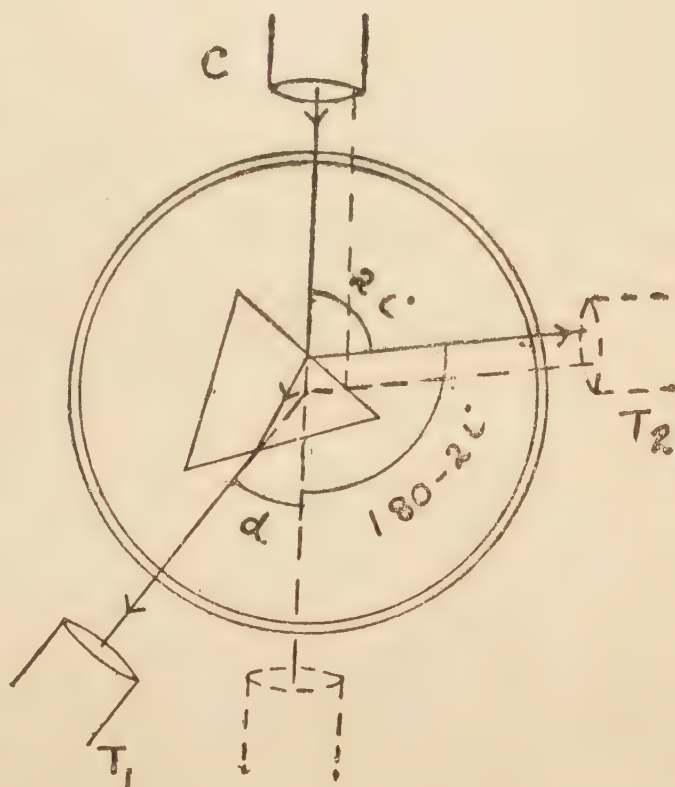


Fig. 125

The platform rests on a vertical rod passing through a sleeve at the centre of the circular disc carrying the verniers. It can be raised and lowered and clamped in any position. It can also be independently rotated about a vertical axis, passing through its centre, when the circular disc is fixed.

Now loosen the clamp and slowly rotate the platform alone so that the reflected image is received in the telescope and the fixed edge of the slit coincides with the point of inter-section of the cross-wires. Take care that the position of the circular disc carrying the verniers is not disturbed. Since the angle between the collimator and the telescope is $2i$, the angle of incidence is i . Release the telescope, turn it round to T_1 to receive the refracted image. Adjust it, so that the point of inter-section of

the cross-wires coincides with the fixed edge of the slit. Note the reading. The difference between this reading and the direct reading will give the angle of deviation corresponding to the angle of incidence i . Remember that the value will be correct, only if the circular disc carrying the verniers had not been disturbed during the above manipulation.

Start with the value of i at 35° and find the angle of deviation. Repeat the experiment for values of i equal to 40° , 45° , 50° , 55° , 60° and 65° and find the angle of deviation corresponding to each angle of incidence. Depending on the material of the glass, for angles of incidence less than 35° and greater than 65° , there may not be any refracted ray.

Tabulate the results as follows:—

Least count of vernier	= , 1'.	
	Vernier A.	Vernier B.
Direct reading.	$0^\circ 2'$	$180^\circ 0'$.

Angle of incidence	Reading of				Angle of deviation	
	Reflected ray		Refracted ray			
	Vernier A	Vernier B	Vernier A	Vernier B	Vernier A	Vernier B
35°	110°2'	290°0'	316°32'	136°30'	43°30'	43°30'
40°	100°2'	280°0'	319°46'	139°44'	40°16'	40°16'
45°	90°2'	270°0'	320°54'	140°54'	39°8'	39°6'
50°	80°2'	260°0'	321°4'	141°3'	38°58'	38°57'
55°	70°2'	250°0'	320°27'	140°27'	39°35'	39°33'
60°	60°2'	240°0'	319°19'	139°18'	40°43'	40°42'
65°	50°2'	230°0'	307°27'	127°26'	42°35'	42°34'

Graph :—Represent angles of incidence along the X axis and angles of deviation along the Y axis. Plot a graph. Draw a smooth curve through the points. You will get a symmetrical curve with a minimum. From the curve, read the angle of

minimum deviation and the angle of incidence at the position of minimum deviation.

You will find that for any other angle of deviation, there are two angles of incidence, one greater than the angle of incidence at the position of minimum deviation and the other less. The two are *conjugate* or inter-changeable positions.

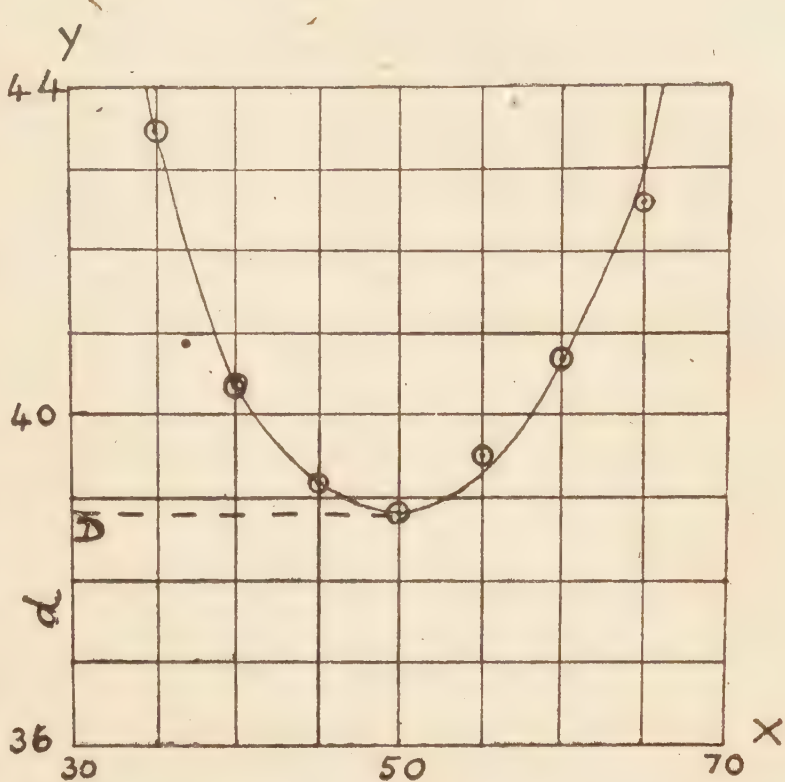


Fig. 126

If i is the angle of incidence at the position of minimum deviation, D the angle of minimum deviation, and A the angle of the prism, then

$$A = (2 i - D).$$

If i_1 and i_2 are the angles of incidence for any other angle of deviation d , then

$$A = i_1 + i_2 - d.$$

Thus, you can find the value of A from the graph.

Angle of deviation d	Angles of incidence		$A = i_1 + i_2 - d$
	i_1	i_2	

∴ Mean $A =$

Calculate μ from the known values of D and A .

Note.—You have been asked to fix the circular disc in the prism-table and only manipulate the platform at the top for

altering the position of the prism. This is to get over the difficulty of having to take the direct reading every time. The above manipulation may be difficult, particularly with an old spectrometer. In such a case, you need not try to keep the direct reading constant. After taking the reading of the refracted ray, take the direct reading and find the angle of deviation. Use this direct reading to adjust the position of the telescope for the next angle of incidence. Though this may involve extra trouble, it is safer.

EXPERIMENT 61

SPECTROMETER

$(I_1 - I_2)$ CURVE AND STOKE'S FORMULA

Aim :—To measure the angles of emergence i_2 for various angles of incidence i_1 and draw the $(i_1 - i_2)$ curve for a prism and calculate its refractive index, using Stokes' formula.

Apparatus required :—Spectrometer, sodium flame, equilateral prism.

(A) $(I_1 - I_2)$ CURVE

Procedure :—Adjust the eye-piece, so that the cross-wires are seen distinctly. Adjust the collimator and telescope for parallel rays and level the prism-table.

Illuminate the slit with sodium light. Turn the telescope so as to be in a line with the collimator. Adjust it, so that the point of inter-section of the cross-wires coincides with the fixed edge of the slit. Fix the prism-table. Read the scale and both the verniers and note down the readings. [It will be convenient, if these readings are adjusted to be 0° and 180° respectively. This can be done by fixing the telescope and rotating the prism-table.] This is the direct reading. Fix the prism-table.

Set the prism on the platform in the prism-table with its centre at the centre of the platform and one of the polished faces facing the collimator.

From the direct reading, subtract $(180 - 2 i_1)$, where i_1 is the required angle of incidence at which the prism has to be set. Turn the telescope and set it at that reading (T_2).

Loosen the clamp used for fixing the platform on the prism-table. Without disturbing the position of the circular disc carrying the verniers, slowly rotate the platform alone, so that the reflected image comes into the field of view. Carefully adjust it so that the fixed edge of the slit coincides with the point of intersection of the cross-wires.

Release the telescope and turn it round to get the refracted image. Adjust it, so that the fixed edge of the slit coincides with the point of intersection of the cross-wires. Fix the telescope (T_1). Read the scale and the verniers and note down the readings.

Turn the platform alone slowly, without disturbing the positions of the circular disc and the telescope, till the other refracted image comes into the field of view of the telescope. [Except in the position of mini-

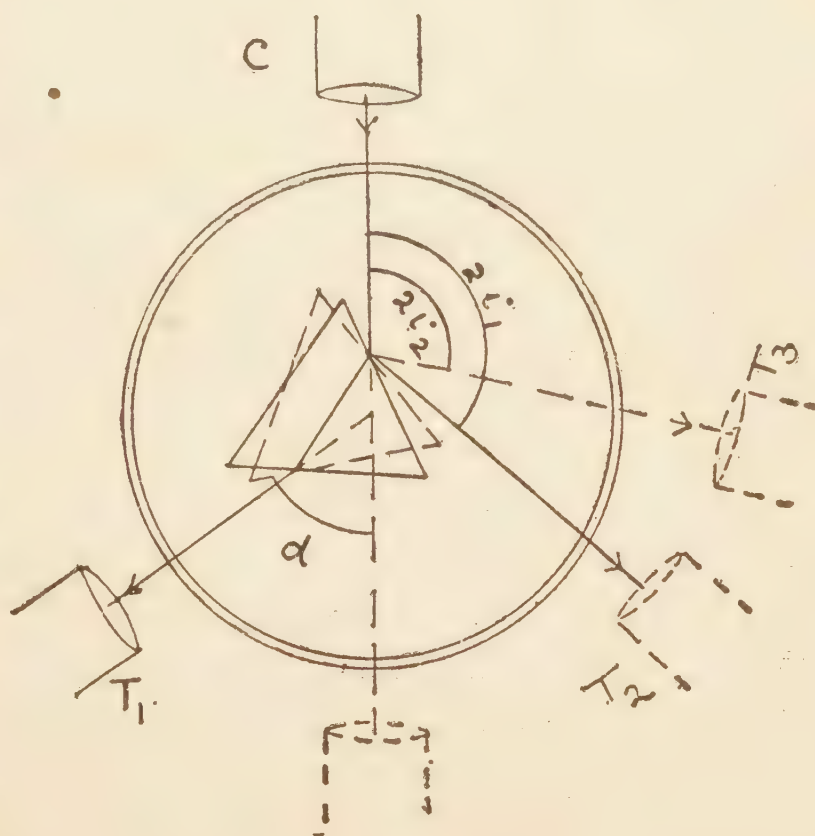


Fig. 127

mum deviation, for every other position there are two angles of incidence, for which the deviation will be the same.] Adjust the platform carefully, so that the fixed edge of the slit coincides with the point of intersection of the cross-wires. Clamp the platform. Release the telescope. Turn it round and get the reflected image from the other face, in its altered position (T_3). Adjust it, so that the point of intersection of the cross-wires coincides with the fixed edge of the slit. Read the scale and the verniers and note the reading. The difference between this reading and the direct reading will give

$(180 - 2 i_2)$, where i_2 is the angle of incidence in the second position of the prism. Calculate i_2 .

For a prism, the angle of incidence and the angle of emergence are inter-changeable. When one of them is the angle of incidence, the other will be the angle of emergence and *vice versa*. Hence, i_1 and i_2 above, represent the angles of incidence and emergence, for the angle of deviation d .

Starting with the angle of incidence i_1 at 35° , find the value of i_2 . Repeat the experiment for values of i_1 , 40° , 45° , 50° , 55° , 60° and 65° and determine the corresponding value of i_2 for each.

Note.—It is convenient to maintain the direct reading constant, by fixing the circular disc carrying the verniers and manipulating the platform alone. This requires skill. It is also possible only, if the spectrometer is in very good condition. So, you may determine the direct reading, every time the prism-table is rotated for getting the image into the field of view of the telescope and use it. Though this is more laborious, it is safer.

Tabulate the readings as follows :—

Least count of the vernier = 1'

Angle of incidence i_1	$(180 - 2i_1)$	Reading of				$(180 - 2i_2)$		Angle of emergence i_2
		Reflected ray		Direct ray				
		Vernier A	Vernier B	Vernier A	Vernier B	Vernier A	Vernier B	
35°	110°	65°35'	245°37'	20°1'	200°1'	45°34'	45°36'	67°13'
40°	100°	70°39'	250°40'	9°33'	189°33'	61°6'	61°7'	64°27'
45°	90°	81°53'	261°52'	8°14'	188°15'	73°39'	73°37'	53°11'
50°	80°	85°31'	265°31'	5°27'	185°27'	80°4'	80°4'	49°58'
55°	70°	84°22'	264°21'	351°12'	171°11'	93°10'	93°10'	43°25'
60°	60°	91°23'	271°23'	350°30'	170°31'	100°53'	100°52'	39°34'
65°	50°	94°20'	274°20'	347°7'	167°8'	107°13'	107°12'	36°24'

[In the above set of readings the direct reading was *not* maintained constant. After taking the reading of the second reflected ray, the direct reading was taken every time.]

Graph :—Represent i_1 along the X axis and i_2 along the Y axis. Take (1) the same scale in both axes and (2) the same value of the angles at the origin.

Plot the points and draw a smooth curve through them. You will get a hyperbola. Draw the bisector at the origin. The point where it cuts the curve will correspond to the angle of incidence at the position of minimum deviation.

If A is the angle of the prism and i , the angle of incidence in the position of minimum deviation,

$$D = 2i - A.$$

where D is the angle of minimum deviation. Find D from the known values of i and A . Calculate the refractive index μ .

$$\text{Refractive index } \mu = \frac{\sin \frac{(D + A)}{2}}{\sin \frac{A}{2}}$$

$$= \frac{\sin \frac{i}{2}}{\sin \frac{A}{2}} \quad \left[\text{since } i = \frac{D + A}{2} \right]$$

(B) STOKES'S FORMULA

Consider the refraction of a ray of light through a prism. Let i_1 be the angle of incidence, and r_1 , the angle of refraction at the first face, r_2 the angle of incidence and i_2 , the angle of refraction (emergence) at the second face, d the angle of deviation for the ray and A , the angle of the prism. Then

$$\mu = \frac{\sin i_1}{\sin r_1} = \frac{\sin i_2}{\sin r_2}.$$

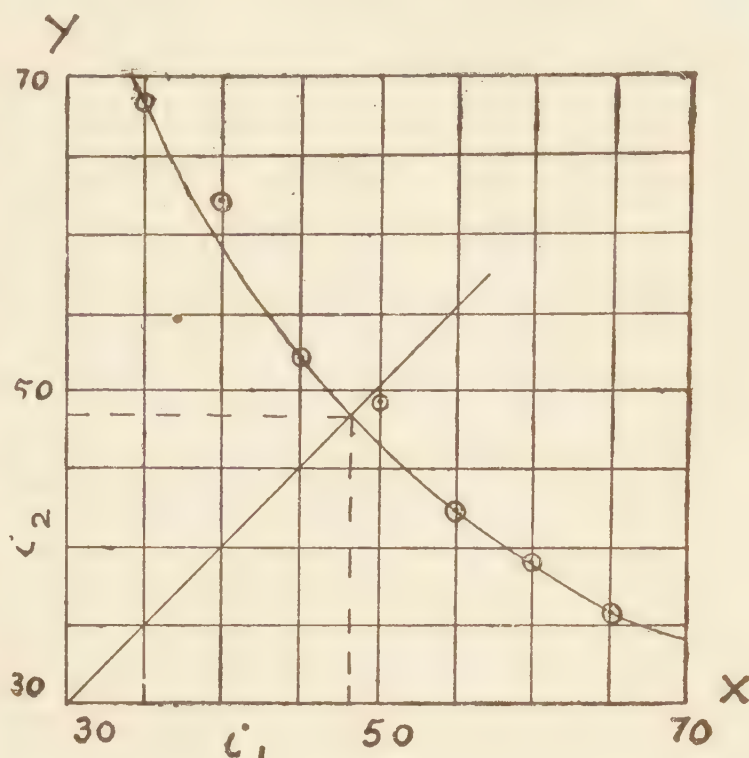


Fig. 128

From this, the following expression can be derived.

$$\frac{\tan \left(\frac{i_1 + i_2}{2} \right)}{\tan \left(\frac{i_1 - i_2}{2} \right)} = \frac{\tan \left(\frac{r_1 + r_2}{2} \right)}{\tan \left(\frac{r_1 - r_2}{2} \right)}$$

It is known, that $(r_1 + r_2) = A$.

$$\therefore \tan \left(\frac{r_1 - r_2}{2} \right) = \frac{\tan \frac{A}{2} \cdot \tan \left(\frac{i_1 - i_2}{2} \right)}{\tan \left(\frac{i_1 + i_2}{2} \right)}$$

i_1, i_2 and A are known,

$\therefore \tan \left(\frac{r_1 - r_2}{2} \right)$ can be calculated. Hence, $(r_1 - r_2)$ is known. Since $r_1 + r_2 = A$, r_1 and r_2 can be calculated. i_1, i_2, r_1 and r_2 are known. So, μ can be calculated.

Tabulate the readings as follows:—

[Angle of the Prism = $60^\circ 10'$].

i_1	i_2	r_1	r_2	$\frac{\sin i_1}{\sin r_1}$	$\frac{\sin i_2}{\sin r_2}$
35°	$67^\circ 13'$	$22^\circ 23'$	$37^\circ 47'$	1.505	1.505
45°	$53^\circ 11'$	$28^\circ 2'$	$32^\circ 8'$	1.505	1.507
55°	$43^\circ 25'$	$32^\circ 59'$	$27^\circ 11'$	1.505	1.504
65°	$36^\circ 24'$	$37^\circ 0'$	$23^\circ 10'$	1.506	1.505

$\therefore$ Average refractive index of sodium light = 1.505

EXPERIMENT 62

SPECTROMETER

SMALL-ANGLED PRISM

Aim :—To determine the refractive index of the material of a small-angled prism.

Apparatus required :—Spectrometer, small-angled prism, sodium light.

Procedure :—Adjust the eye-piece, so that the cross-wires are distinctly seen. Adjust the telescope and collimator for parallel rays. Level the prism-table. Illuminate the slit with sodium light.

(A) Angle of the prism

Set the prism on the prism-table with its refracting edge at the centre of the table and facing the collimator. Turn the telescope, so that the image of the slit due to reflection at one of the faces is seen in the field of view. Adjust it, so that the point of inter-section of the cross-wires coincides with the fixed edge of the slit. Read the scale and the verniers and note the readings.

Fix the telescope. Rotate the prism-table, till the reflected image due to the other face is seen in the field of view. Adjust the prism-table so that the fixed edge of the slit coincides with the point of inter-section of the cross-wires. Read the scale and the verniers and note down the readings.

Find the difference between the two readings and subtract it from 180° . That will give the angle of the prism. [This method is better for this experiment, than the other method in which the prism is kept fixed and the telescope is rotated.]

Change the position of the prism and repeat the experiment. Take two or three readings.

(B) Angle of deviation for normal incidence

Procedure :—Bring the telescope in a line with the collimator and take the direct reading. Fix the prism-table. From the direct reading subtract 90° . Turn the telescope and set it for this reading.

Fix the telescope. Turn the prism-table, so that the reflected image due to one of the faces comes into the field of view. Adjust, so that the point of inter-section of the cross-wires coincides with the fixed edge of the slit. Take the reading. Subtract from it, 45° . Rotate the prism-table and set it for this reading. The face of the prism near the collimator will now be normal to the axis of the collimator. Fix the prism-table.

Release the telescope and turn it, so that the refracted image of the slit is seen in it. Adjust it, so that the fixed edge of the slit coincides with the point of inter-section of the cross-wires. Read the scale and the verniers. Note down the readings.

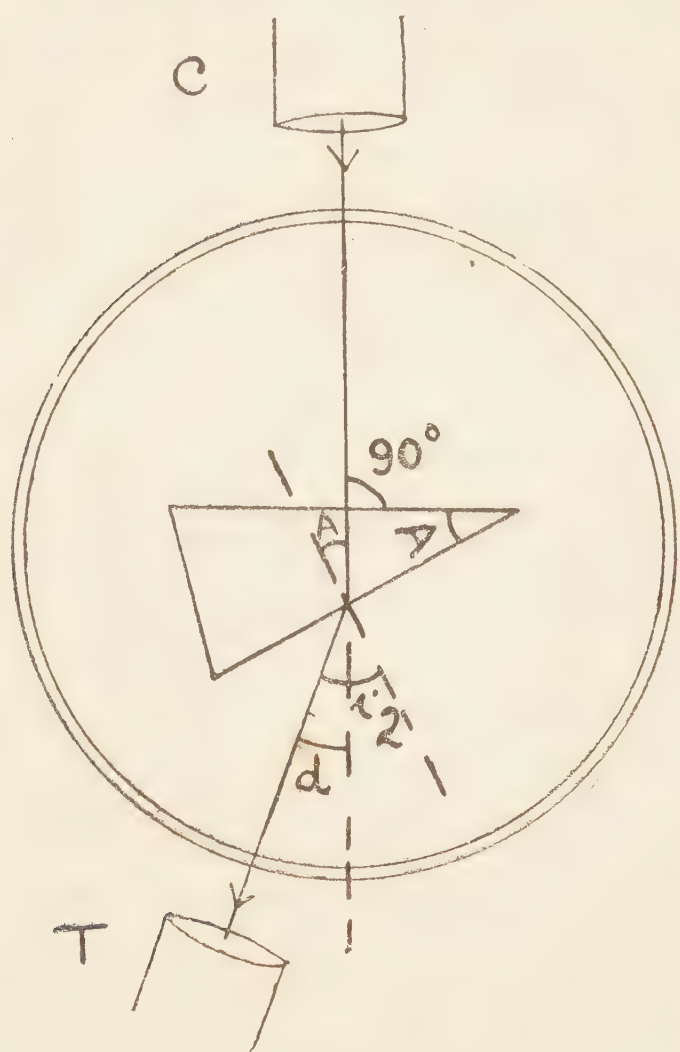


Fig. 129

Remove the prism. Bring the telescope in a line with the collimator. Adjust it, so that the point of inter-section of the cross-wires and the fixed edge of the slit coincide. Take the reading. The difference between the two readings gives the angle of deviation.

Repeat the experiment by setting the other face for normal incidence and measuring the angle of deviation.

If A is the angle of the prism and d, the angle of deviation for a ray incident normally at the first face,

Refractive Index μ = $\frac{\sin (d + A)}{\sin A}$

Tabulate the readings as follows :—

(1) Angle of the prism.

Least count = 1'.

Reading of prism-table				Difference in reading θ		Angle of the prism (180— θ)
Position I		Position II				
Vernier A	Vernier B	Vernier A	Vernier B	Vernier A	Vernier B	
Mean						

II. Angle of deviation :—

	Position I			Position II		
	Reading of refracted ray	Direct reading	Angle of deviation	Reading of refracted ray	Direct reading	Angle of deviation
Vernier A						
Vernier B						

∴ Mean angle of deviation =

From the formula, calculate μ , using the values of A and d.

(C) Minimum deviation

Procedure :—Set the prism with its centre at the centre of the table. Turn the telescope and get the refracted image of the slit in the field of view. Turn the prism-table and the telescope and adjust the prism for the position of minimum deviation. Set the point of inter-section of the cross-wires on the fixed edge of the slit and take the reading. Remove the prism. Bring the telescope in a line with the collimator. Adjust, so that the point of inter-section of the cross-wires coincides with the fixed edge of the slit and take the direct reading. The difference between the two readings gives the angle of minimum deviation.

Repeat the experiment with the rays of light from the collimator incident on the other face.

Alter the position of the prism on the prism-table. Repeat the experiment and take two or three readings. Find the mean value of the angle of minimum deviation.

From the known values of the angle of the prism and the angle of minimum deviation, calculate the refractive index, using the formula,

$$\mu = \frac{\sin \frac{D + A}{2}}{\sin \frac{A}{2}}$$

(D) Angle of incidence at the first face when refracted ray emerges normally from the second face.

Procedure :—Set the prism with its centre, at the centre of the table, and with its face normal to the rays coming from the collimator, following the method given in (B).

Turn the telescope so that the refracted image is seen in the field of view. Adjust it so that the point of inter-section of the cross-wires and the fixed edge of the slit coincide.

Fix the telescope. Rotate the prism-table, so that the image moves towards the position of minimum deviation, retraces its

path and again coincides with the cross-wires. Adjust the prism-table, so that the point of inter-section of the cross-wires and the fixed edge of the slit coincide. Read the scale and the verniers. Note down the reading.

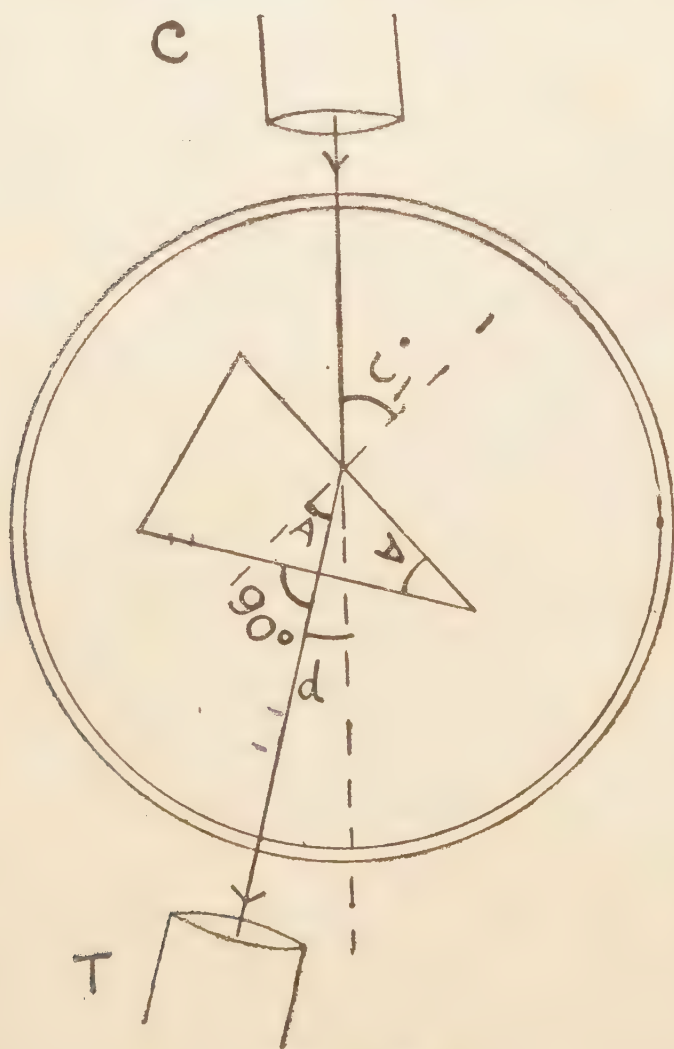


Fig. 130

[In the former position of the prism, the incident ray was normal to the first face of the prism. In both the positions, the angle of deviation is the same. Hence, in the latter position of the prism, the emergent ray must be normal to the second face of the prism.]

Fix the prism-table. Release the telescope. Turn it round so that the reflected image from the first face is seen in the field of view. Adjust it, so that the point of the inter-section of the cross-wires coincides with the fixed edge of the slit. Take the reading.

Remove the prism. Bring the telescope in a line with the collimator and take the direct reading. The difference between the two readings gives $(180 - 2 i_1)$. From this, calculate i_1 the

angle of incidence at the first face, when the refracted ray emerges normally from the second face.

Now, i_1 is the angle of incidence at the first face. The angle of refraction is equal to A , the angle of the prism, since the refracted ray is normal to the second face. Hence,

$$\text{Refractive Index } \mu = \frac{\sin i_1}{\sin A}.$$

Tabulate the readings taken. .

EXPERIMENT 63

SPECTROMETER

TOTAL REFLECTION—REFRACTIVE INDEX

Aim :--To determine the critical angle of glass using a prism and the spectrometer.

Apparatus required --Spectrometer, a glass prism with one of its faces unpolished, sodium light.

Procedure :--Adjust the eye-piece, so that the cross-wires are distinctly seen. Adjust the telescope and collimator for parallel rays. Level the prism-table. Illuminate the slit with sodium light.

Determine the angle of the prism by one of the methods described in experiment 58.

Set the sodium light, so that its light falls on the unpolished (or ground) face of the prism. Turn round the telescope to face one of the polished sides of the prism. You will observe two regions, illuminated to different extents and separated by a vertical line. Make the point of inter-section of the cross-wires coincide with the line. Read the scale and the verniers and note down the reading.

Rotate the telescope to face the other polished side. Adjust it, so that the point of inter-section of the cross-wires coincides with the line of separation of the brighter from the less bright region. Take the reading.

Let the difference between the two readings be θ . Let r be the angle between the emergent ray and the normal at the line of separation. Let A be the angle of the prism. Then, if the telescope is rotated from one side to the other round the base,

$$\theta = (180 - 2r) + A$$

$$\therefore r = \frac{180 + A - \theta}{2}$$

If the telescope is rotated from one side to the other round the refracting edge of the prism, $\theta = 180 + 2r + A$.

$$\text{Then, } r = \frac{\theta - 180 - A}{2}$$

Let C be the critical angle and i the angle of incidence for which r is the angle of refraction. Then,

$$\frac{\sin r}{\sin i} = \mu \text{ and } \sin C = \frac{1}{\mu}.$$

$$\text{Also, } C + i = A.$$

$$\begin{aligned} \therefore \sin r &= \mu \sin i \\ &= \mu \sin (A - C). \\ &= \mu \sin A \cdot \cos C \\ &\quad - \mu \cos A \cdot \sin C \\ &= \sin A \cdot \cot C \\ &\quad - \cos A. \end{aligned}$$

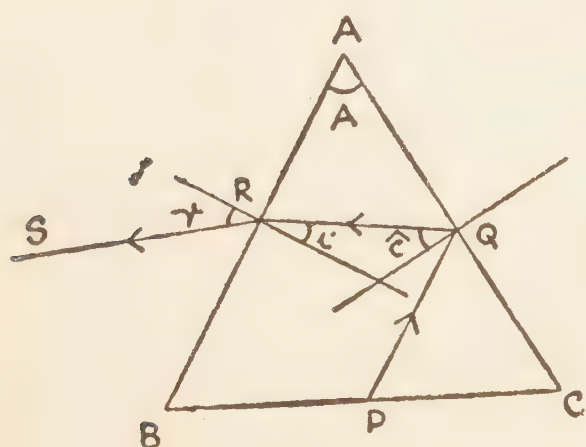


Fig. 131

$$\therefore \cot C = \frac{\sin r + \cos A}{\sin A}$$

$$\begin{aligned} \text{Now, } \mu^2 &= \frac{1}{\sin^2 C} = 1 + \cot^2 C \\ &= 1 + \left(\frac{\sin r + \cos A}{\sin A} \right)^2 \end{aligned}$$

From the known values of A and r , calculate the refractive index μ .

[Let ABC represent the prism. Let BC be the ground face and AB, AC the polished faces. When BC is illuminated, every point in it sends out light in all directions. Take a point P in it. Consider the ray PQ incident at the face AC at an angle slightly greater than the critical angle C . You can take it to be practi-

cally equal to C . Let it be reflected along QR , incident at face AB at angle i and emerge along RS at angle r . Rays from other points on BC parallel to PQ will all emerge parallel to RS and get focussed along the line of separation of the two regions. Rays from P incident on AC at angles less than C are *partially* reflected, while rays incident on AC at angles greater than C are *totally reflected*. All these rays emerge from face AB in a different direction. So you get two regions, one brighter than the other, separated by a line represented by RS .]

EXPERIMENT 64.

SPECTROMETER

SOLAR SPECTRUM—DISPERSIVE POWER OF PRISM

Aim :—To determine the refractive indices of the Fraunhofer's lines in the Solar spectrum formed by a prism and to calculate its dispersive power.

Apparatus required :—Spectrometer, glass prism, plane mirror.

(A) Fraunhofer's lines

Procedure :—Adjust the eye-piece in the telescope, so that the cross-wires are seen distinctly. Adjust the telescope and the collimator for parallel rays. Level the prism-table.

Mount the plane mirror on a stand. Set up the stand at a place where sunlight falls on it. Adjust the plane of the mirror, so that the reflected beam of sunlight is horizontal. As the sun is constantly on the move, the plane of the mirror will have to be adjusted periodically to make the reflected beam fall on the slit of the collimator horizontally.

Set up the spectrometer, so that the reflected beam of sunlight falls on the slit of the collimator horizontally and passes along its axis. To test this, examine the lens of the collimator. If the outline of the slit due to the sunlight falling on the lens is seen at its centre, it means that the light travels along the axis of the collimator.

Place the prism on the prism-table with the refracting edge facing the collimator. Determine the angle of the prism by one of the methods described in experiment 58.

Adjust the position of the prism, so that one of the faces receives the light emerging from the collimator. Rotate the telescope to receive the emergent beam. You will see a continuous spectrum in the field of view with the red end deviated least and the violet end deviated most.

Slowly reduce the width of the slit in the collimator. If the slit is very narrow, the dark lines in the solar spectrum, known as the Fraunhofer's lines, will make their appearance. These dark lines are vertical and found in every part of the spectrum from the red to the violet end. [You will also notice horizontal dark lines making their appearance, when the slit is made very narrow. They are due to tiny dust particles on the two sides of the slit. These particles can be removed by cleaning the slit edges with a pointed stick made of hard wood.] Learn to identify the more prominent among the lines—B, C, in the red region, D in the yellow region, E, b in the green region, F and G in the blue-violet region.

Start with the B line. Fix the prism-table. Loosen the platform carrying the prism and turn it to and fro so that the prism is in the position of minimum deviation for the B line. Set the point of inter-section of the cross-wires on the B line and take the reading.

Next, adjust the platform, so that the prism is in the position of minimum deviation for the C line. Make the point of inter-section of the cross-wires coincide with the C line and take the reading.

Repeat the experiment, adjusting the platform carrying the prism, so that the prism is in the position of minimum deviation for each one of the lines mentioned above — D, E, b, F and G. Make the point of inter-section of the cross-wires coincide with each one of the lines in the position of minimum deviation and take the corresponding readings.

II.

Line observed	Angle of minimum deviation	Refractive Index
B		
C		
D		
E		
b		
F		
G		

(B) Dispersive power of a prism

Procedure :—The dispersive power of a prism is calculated from the formula,

$$\text{Dispersive power} = \frac{\mu_F - \mu_C}{\mu_D - 1}$$

where μ_F , μ_D and μ_C are the refractive indices of the F, D, and C lines respectively for the prism.

From the values of μ obtained for the F, D and C lines, in the above experiment, calculate the dispersive power of the prism.

Note :—It is not always possible or convenient to perform an experiment using sunlight and calculate the dispersive power.

A hydrogen discharge tube can be used instead. The refractive indices of the lines in the red and the violet regions can be determined and used for calculating the dispersive power.

When the dispersive power is given, the particular lines chosen in the red and violet regions for the calculation must be specified.

EXPERIMENT 65**NEWTON'S RINGS**

Aim :—To determine the wave-length of sodium light by forming Newton's Rings.

Apparatus required :—Newton's rings apparatus, vernier microscope, sodium lamp, mercury float, plane mirror.

Description of apparatus :—A long focus double convex lens or plano-convex lens (about 3 to 4 cms. in diameter) is placed

on an optically plane glass plate, with the convex surface resting on it. A glass plate with parallel sides is fitted above the combination at an inclination of 45° to the horizontal. A microscope is set up above the plate with its axis vertical and passing through the centre of the lens. It is used for measuring the diameters of the rings formed in the air film round the point of contact of the lens and plate.

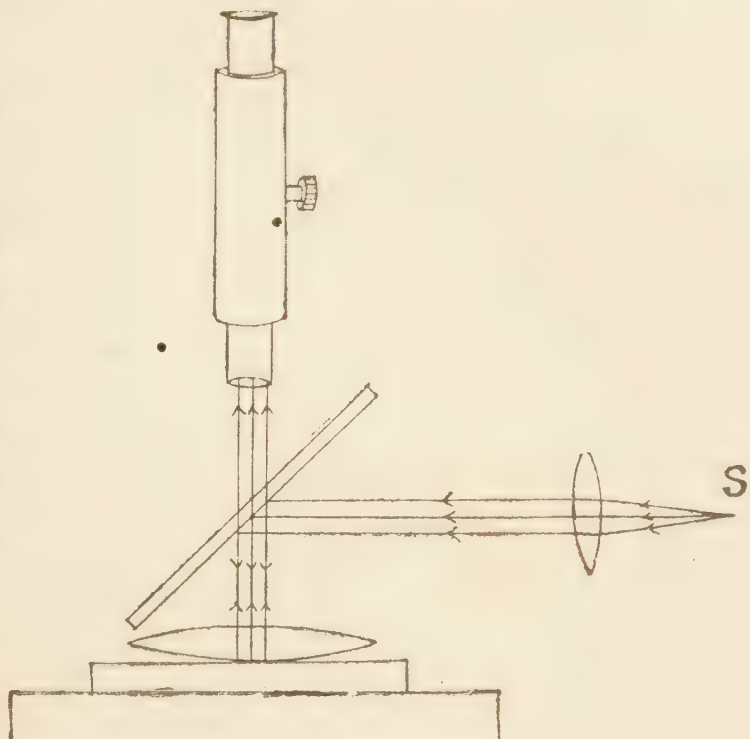


Fig. 132

Light from a sodium lamp, rendered parallel by a convex lens, falls horizontally on the inclined glass plate. It is reflected on to the convex lens and the plate under it. They retrace their path and pass through the microscope. Due to interference between the rays of light reflected from the lower surface of the lens and the top surface of the plane glass plate, dark and bright rings are seen in the air film between the two.

Procedure :—Adjust the eye-piece of the microscope so that the cross-wires are distinctly seen. Raise or lower the microscope till the concentric dark and bright rings, formed round the point of contact of the lens and plate, are in clear focus. Gently tilt the glass plate, so that the rings seen have maximum brightness.

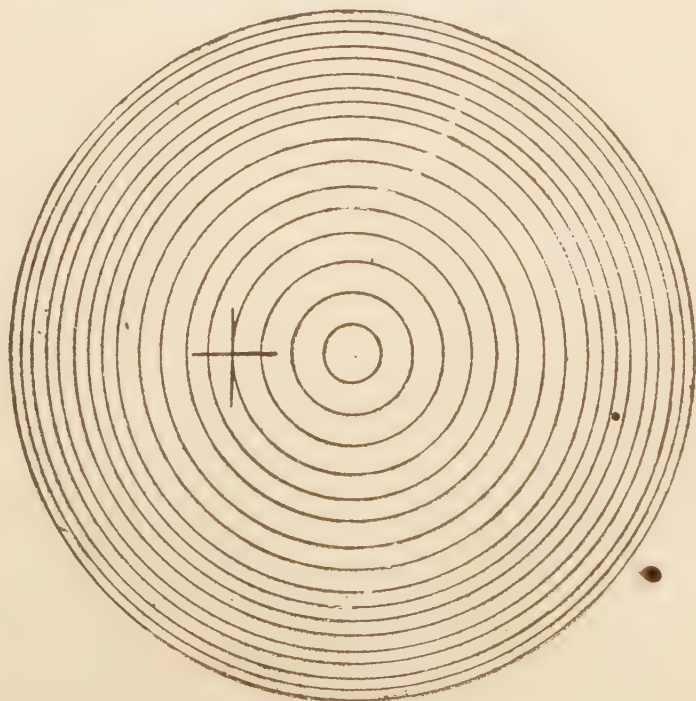


Fig. 133

Find the least count of the vernier attached to the horizontal scale in the microscope. Move the microscope and see, if the

point of intersection of the cross-wires moves over the rings along their common diameter. Adjust the disposition of the cross-wires, so that one of them is perpendicular and the other parallel to the line of movement of the microscope.

Move the microscope, so that the normal cross-wire passes over about 20 rings, say to the left. Then, adjust the microscope, so that the normal cross-wire is at the middle of the 20th dark ring. Read the scale and the vernier and note down the reading.

Move the microscope to the right, so that the cross-wire passes over to the next ring towards the centre. Make the cross-wire coincide with the 19th dark ring and adjust it, so that it is at the centre of the ring. Take the reading. Move the microscope and make the cross-wire coincide with the mid-points of consecutive dark rings. Take the corresponding readings. Stop at the 10th ring.

Move the microscope, so that the cross-wire passes to the other side of the centre of the ring system. Make it coincide with the centres of consecutive dark rings, commencing with the 10th ring. Take the readings in each case. Stop at the 20th ring.

Reverse the motion of the microscope. Take the readings, when the cross-wire coincides with the centres of the consecutive dark rings commencing from the 20th ring on the right of the centre. Stop at the 10th ring. Move over to the left of the centre. Take readings corresponding to the centres of the dark rings commencing from the 10th ring. Stop at the 20th ring.

The difference between the readings on the left and on the right for any particular ring gives its diameter.

Remove the lens and determine the radius of curvature of the surface which was in contact with the plane glass plate. Do this by any one of the methods described in experiment 54. The simplest is the following method. Place the lens on a plane mirror. Mount a knitting needle above it horizontally. Adjust it, so that it coincides with its own image without parallax. The distance between the needle and the centre of the lens measured along the principal axis of the lens is equal to its focal length.

Float the lens on a pool of mercury in a dish, with the surface that was used for forming rings, in contact with the mercury. Adjust the needle above it, so that it coincides without parallax

with its image formed by reflection at the surface in contact with the mercury. Measure the distance of the needle from the centre of the lens along its principal axis. Then, if d is the distance measured and f , the focal length of the lens,

$$R = \frac{f d}{f - d} \quad (\text{Boys' method})$$

The diameter of the X th dark ring is given by the formula,

$$D_x^2 = 4 X \lambda R$$

where D_x is the diameter of the X th dark ring, λ the wave length of light and R the radius of curvature of the surface used for forming rings with the plane surface.

There is, generally, some uncertainty in counting the rings from the centre. So, the following method of calculation which eliminates X , is adopted.

$$D_x^2 = 4 X \lambda R$$

$$D_{(n+x)}^2 = 4 (N + X) \lambda R$$

$$\therefore D_{(n+x)}^2 - D_x^2 = 4N \lambda R$$

From the equation, calculate λ .

Tabulate the results as follows :—

1. Least count of the microscope =

No. of ring	Reading of ring			Reading of ring			Diameter of ring D
	Left			Right			
	For- ward	Back- ward	Mean	For- ward	Back- ward	Mean	
20							
19							
18							
17							
16							
15.							
14							
13							
12							
11							
10							

II

No. of ring	Diameter D_x	No. of ring	Diameter $D (n + x)$	$D^2 (n + x) - D^2_x$
10		15		
11		16		
12		17		
13		18		
14		19		
Mean				

III. Focal length f of lens =
(by plane mirror).

Distance d measured by Boys' method.

$$\therefore \text{Radius of curvature } R \text{ of } \left. \begin{array}{l} \text{surface} \\ \dots \end{array} \right\} = \frac{f d}{f - d}$$

$$\therefore \lambda = \frac{D^2 (n + x) - D^2_x}{4 n R.}$$

Repeat the experiment with the other surface of the lens (if it is convex) in contact with the glass plate and take a similar set of readings.

Note :—The surfaces of the lens and the plate must be clean and free from dust. When the convex surface in contact with plate has a large radius of curvature, the rings are broad, while, when the radius of curvature is small, the rings are narrow. If the radius of curvature is about 80 cms. to 120 cms. the rings formed are convenient for measurement. When the rings formed are close together, readings of alternate rings may be taken. Take particular care in counting the rings, as, if a slip is made, inaccuracy will creep in and the result will be unreliable.

The method can be used for measuring the radius of curvature of a convex surface, assuming the value of λ , the wave-length of sodium light.

EXPERIMENT 66

FRESNEL'S BIPRISM

Aim :—To form interference bands using Fresnel's biprism and determine the wave-length of sodium light.

Apparatus required:—Optical bench with accessories, biprism, convex lens, sodium lamp.

Description of apparatus :—The optical bench used for this experiment consists of a long, heavy metal bed about $1\frac{1}{2}$ to 2 metres long. It is fitted with levelling screws to adjust it to be horizontal. It has rails at the top on either side. A number of uprights are provided which slide along the rails on the bed. A scale is engraved on one of the rails. The bases of the uprights carry verniers which move by the side of the scale. The uprights are made up of hollow pillars mounted on cast iron bases. Rods carrying the holders for the slit, biprism, etc. are inserted into these pillars. They can be raised or lowered by rack and pinion arrangement. To the bases of the uprights are fitted, in addition, slides and screws, for moving the uprights across the bases, at right angles to the direction of the bed.

Two of the uprights carry the slit and the biprism. The holders are fitted with metal jaws, which serve to keep the slit or biprism firmly gripped. They are further provided with tangent screw arrangement, for rotating them in their own plane round a horizontal axis passing through their centre.

A third upright carries an eye-piece provided with cross-wires. It can be moved transversely by working a micrometer screw fitted to the holder and moving by the side of a linear scale. It enables you to measure the distance passed over by the cross-wires, across the field of view.

A fourth upright carries a lens-holder.

Adjustments :—Move the upright carrying the slit to one end of the bed. Set up a sodium lamp in front of it and illuminate the slit. Move the upright carrying the biprism towards the other, so that the distance between the two is about 10 to 15 cms. Adjust the positions of the uprights on the bed, so that the zeros

on the verniers in their bases coincide with definite divisions on the scale. Adjust their heights, so that the centre of the slit and the centre of the biprism are along the same horizontal line, parallel to the axis of the bed. Rotate them about a horizontal axis using the tangent screws, so that the slit and the edge of the biprism are vertical. The finer adjustment can be done later.

Move the upright with the eye-piece towards the biprism. Raise or lower it, till it is at the same vertical height, as the biprism and the slit.

Adjust the eye-piece, so that the cross-wires are distinctly seen. Look through the eye-piece. If the slit, the centre of the biprism, and the centre of the eye-piece are along the same horizontal line, an image of the illuminated slit will be seen in the field of view.

[If the image is not seen, the eye-piece may be removed. Look towards the biprism and the slit through the socket of the eye-piece. Move the biprism transversely using the tangent screw at the base, till the edge of the prism is seen to coincide with the slit. Replace the eye-piece and readjust it, so that the cross-wires are clearly seen.]

Even if the image of the slit is seen in the field of view, interference bands may not be visible. To get them, first make the slit as narrow as possible. Then, rotate either the slit or the biprism in their own plane, round a horizontal axis using the tangent screw. When the narrow slit and the edge of the biprism are in the same vertical plane, dark and bright vertical bands will make their appearance. Adjust the width of the slit and rotate the biprism *or* slit, till the bands are most distinct.

Move the eye-piece upright away from the biprism. The bands become broader. But, unless the vertical plane passing through slit and the edge of the biprism is parallel to the axis of the bed, the bands will move across the field of view, as the eye-piece is moved away. By working the tangent screws at the base of the uprights, adjust, so that the bands remain at the centre of the field of view, as the eye-piece is moved to and fro along the direction of the bed.

Procedure :—(1) Determination of band-width. Having got well-defined bands, proceed to measure the band-width. Find the least count of the micrometer screw. Move the upright with

the eye-piece to a distance of 15 to 20 cms. from the biprism. Adjust the cross-wires, so that they are equally inclined to the vertical. Move the eye-piece, so that the point of intersection of the cross-wires is at the centre of the first dark band at the extreme right or left. Read the pitch scale and head scale of the micrometer and note down the reading.

Set the point of intersection of the cross-wires at the centres of successive dark bands and note down the readings till you reach the other end. Reverse the direction of motion of the cross-wires. Set them on successive bands and note down the readings.

Move the upright with the eye-piece away from the biprism by 10 cms., 20 cms., and 30 cms. In each position, repeat the experiment. Take the readings, by setting the cross-wires on consecutive bands, when the eye-piece is moved from left to right and *vice-versa*.

(2) **Distance between sources** :—Move the upright carrying the eye-piece to a distance of 80 to 100 cms. from the slit. The distance must be greater than four times the focal length of the convex lens supplied. Without disturbing the positions of the

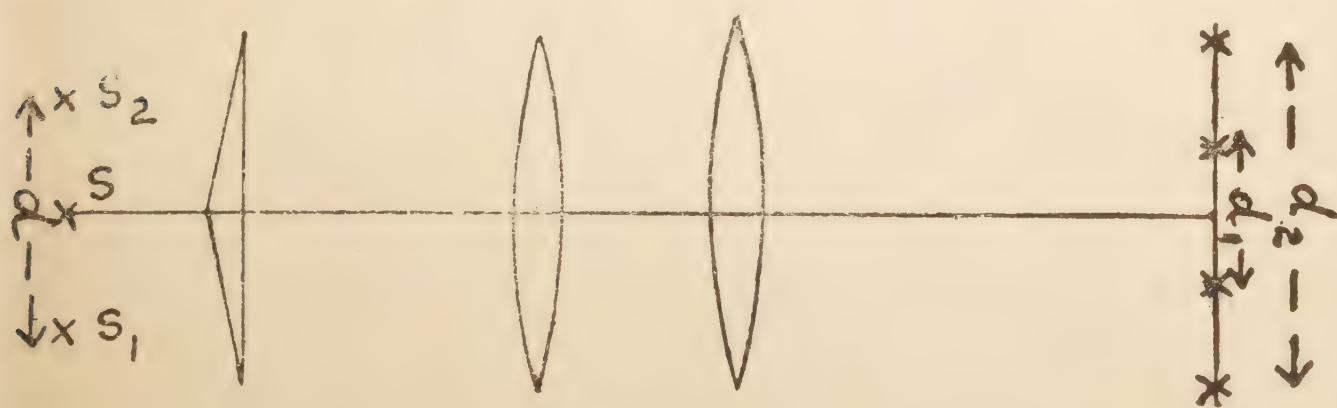


Fig. 134

slit or biprism, introduce the upright carrying the convex lens between the biprism and the eye-piece. Raise the lens so that its principal axis passes through the centres of the slit, the biprism and the eye-piece. Increase the width of the slit slightly.

Keeping the convex lens midway between the slit and the eyepiece, look through the eye-piece. If all the adjustments mentioned had been made carefully, two images of the slit will be seen in the field of view. Move the upright with the convex lens slowly towards the eye-piece, till the two images are in clear focus. Set the cross-wires on the fixed edges of the slits one after another and note the readings on the scale and micrometer.

Slowly move the convex lens away from the eye-piece, till another set of two images of the slit is seen in clear focus. The distance between them will be greater now than in the former position. Set the cross-wires on the fixed edges of the slits one after another and take the corresponding readings on the micro-meter scales. If d_1 is the distance between the images in the first position and d_2 the distance in the second position, then the distance d between the sources is given by

$$d = \sqrt{d_1 d_2}.$$

Calculations :—The angle of the biprism is very nearly equal to 180° . It produces two virtual images S_1, S_2 of the illuminated

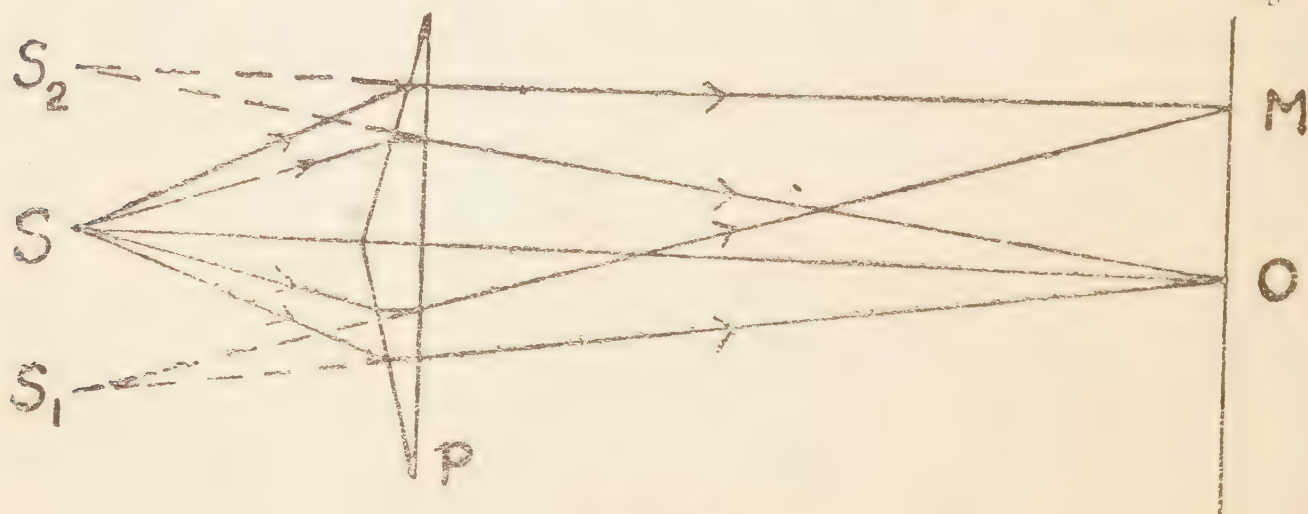


Fig. 135

slit S at the same distance from the edge of the prism as the slit. These two virtual images form two identical sources of light and trains of waves proceeding from them produce interference bands in the focal plane OM of the eye-piece. If D is the distance between the slit and the focal plane of the eye-piece, d the distance between the virtual images of the slit, X the distance between two consecutive bands and λ the wave length, then

$$X = \frac{D}{d} \lambda.$$

From the known value of D , d and X , λ can be calculated.

It is difficult to measure D accurately. The distance between the zeros in the verniers in the uprights carrying the slit and the eye-piece may *not* be equal to the actual distance between the slit and the focal plane of the eye-piece. If this index-error is determined, can be measured with accuracy. [The index-error is found as follows. The upright carrying the biprism is removed. A long straight needle of a known length is mounted horizontally

parallel to the axis of the bed. It is moved, so that one end of it just touches the slit at its middle. The eye-piece is moved and focussed on the other end. The readings on the scale of the uprights carrying the slit and the eye-piece are read. The distance is found. The difference between this distance and the length of the needle is the index-error. It has to be applied to any distance measured between the uprights carrying the slit and the eye-piece.]

The index-error determination and use can, however, be avoided. The band width X_1 is determined when the distance of the upright carrying the eye-piece from the slit, as read on the scale is D . The upright is moved, so that the zero of the vernier attached to it moves through a distance of D_1 cms. Let the band width now be X_2 . Then

$$X_1 = \frac{D}{d} \lambda$$

$$X_2 = \frac{(D + D_1)}{d} \lambda$$

$$\therefore X_2 - X_1 = \frac{D_1 \times \lambda}{d}$$

From this, λ can be calculated.

Tabulate the readings as follows :—

I. Least count of micrometer screw =

(1) Distance between the slit and eyepiece = D cms.

Band No.	Reading			Band No.	Reading			Difference in reading
	Forward	Back-ward	Mean		Forward	Back-ward	Mean	
1				6				
2				7				
3				8				
4				9				
5				10				
•								
Mean								

$\therefore$ Mean width of a band = X_1 cms.

(2) Distance between the slit and the eyepiece $= (D + D_1)$ cms.

Band No.	Reading			Band No.	Reading			Difference in reading
	Forward	Back-ward.	Mean		Forwrd	Back-ward	Mean	
1				6				
2				7				
3				8				
4				9				
5				10				
Mean								

$\therefore$ Mean width of a band $= X_2$ cms.

$\therefore (X_2 - X_1) =$ cms.

II. Distance between the images of the slit formed by the convex lens..

Position I $= d_1$ cms.

Position II $= d_2$ cms.

$$\therefore d = \sqrt{d_1 d_2}$$

From the known values of d ($X_2 - X_1$), D_1 and d , calculate λ .

EXPERIMENT 67

SPECTROMETER

DIFFRACTION GRATING

Aim :—To determine the wave-length of light with a diffraction grating and spectrometer.

Apparatus required :—Spectrometer, plane diffraction grating, sodium or mercury lamp.

Description of grating :—The plane diffraction grating in general use is the replica or photographic reproduction in celluloid of Rowland's grating on which are ruled 14,500 lines per inch. It is fixed on to an optically plane plate of glass. When a

parallel beam of light falls on it, a diffraction pattern with a central maxima, with maxima and minima on either side, is obtained. If the incident light is monochromatic, the maxima are of a single colour. If it is composite, it is split up and the maxima are composed of coloured bands.

It is absolutely essential that the surface of the grating, where the film is fixed, must not be touched with the bare hands or misused. The film may get damaged beyond repair.

(A) Normal incidence

Procedure :—Adjust the eye-piece of the telescope, till the cross-wires are distinctly seen. Focus the telescope and collimator for parallel rays. Level the prism-table, with a spirit level.

Remove the prism clamp and fit up the grating holder on the prism-table. Find the least count of the verniers. Illuminate the slit with sodium light or mercury light.

Place the telescope in a line with the collimator. Adjust it, so that the point of intersection of the cross-wires and the fixed edge of the slit coincide. Read the scale and the two verniers and note down the readings.

Subtract 90° from the direct reading. Rotate the telescope, set it at that reading and fix it.

Insert the grating in the grating-holder with the ruled surface vertical and at the centre of the table, facing the collimator. Rotate the prism-table, so that the grating takes up a position, equally inclined to the axes

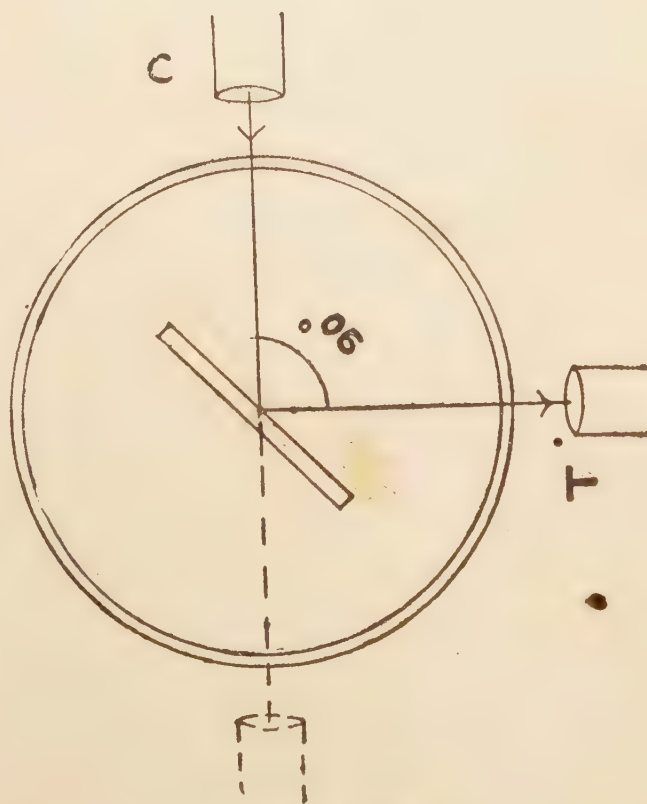


Fig. 136

of the collimator and telescope. Look into the telescope and rotate the prism-table till the image of the slit

reflected from the surface of the grating is seen in the field of view. There will be two images. Take the brighter one. Adjust the

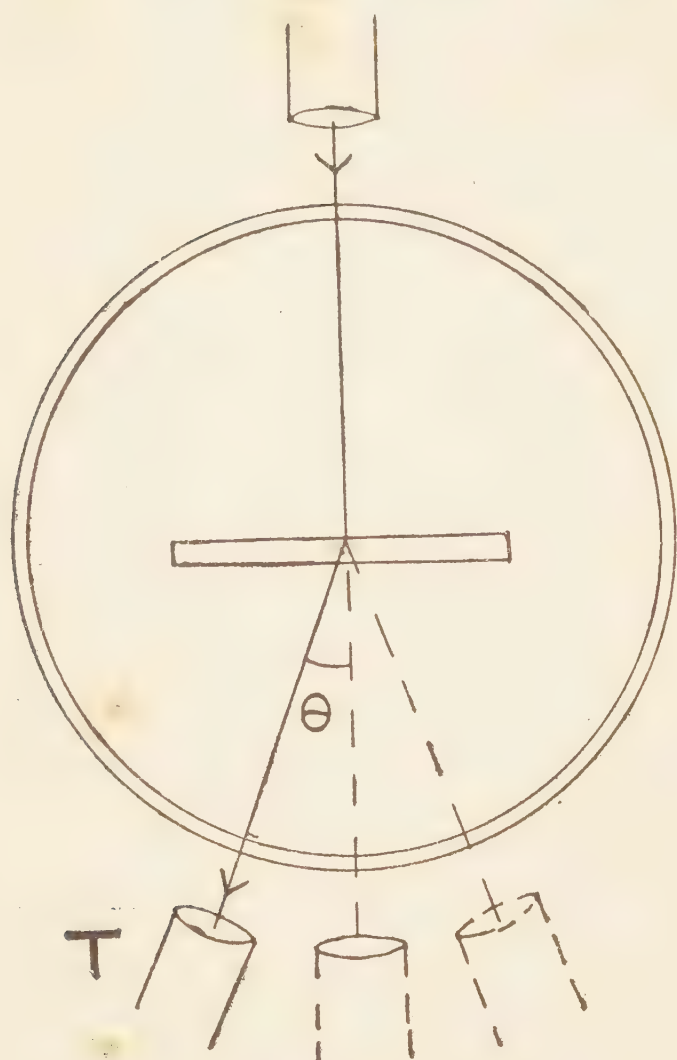


Fig. 137

position of the prism-table, till the point of intersection of the cross-wires coincides with the fixed edge of the slit. Note the reading. Subtract 45° from it. Rotate the prism-table and set it at that reading. Now the surface of the grating is normal to the axis of the collimator. Fix the prism-table.

Release the telescope. Turn it round. Along the direction of the incident beam of light, there will be a bright maximum which is undispersed.

Both to the right and to the left of the centre, there will be seen maxima. The maxima are made up of coloured bands separated from each other. If sodium light is used, two bright yellow bands will be seen, provided the slit is very narrow. With mercury light, four brightly coloured bands will be seen—yellow, green, blue and violet. The set of bands nearest the centre on either side is known as the spectra of the 1st order. The next set of bands are known as the spectra of the 2nd order. Further orders will not be observed with a grating having 14500 lines per inch.

Move the telescope and adjust it, so that the point of intersection of the cross-wires is at the middle of the band nearest to the centre. [Have a narrow slit.] Take the reading. Repeat the adjustment for each of the bands on the left of the centre and on the right of the centre, in both the 1st and the 2nd orders and take readings.

The difference in the readings for any particular coloured band in any order, on the right and on the left of the centre, divided by two gives the angle of diffraction for that band. If θ is the angle of diffraction, n the order of the spectrum, N the number of lines per cm. on the grating and λ , the wave length of the band.

$$\sin \theta = N n \lambda$$

or $\lambda = \frac{\sin \theta}{N n} = \frac{e \sin \theta}{n}$, where e or $\frac{1}{N}$ is called the "grating element." From this the wavelength is calculated.

Tabulate the readings as follows :—

No. of lines per cm. on the grating =

Light used—

Least count of vernier =

Specifi- cation of line	Reading				Difference		Angle of diffraction.	Wave-length $\times 10^8$ cms.
	Left		Right					
	Vernier A	Vernier B	Vernier A	Vernier B	Vernier A	Vernier B		
I	Spectrum of the		1st order					
II	Spectrum of the		2nd order					

(B) Minimum Deviation

Procedure :—After having found the angles of diffraction of the maxima, for light incident normally on the grating, release the prism-table. Adjust the telescope, so that the intersection of the cross-wires coincides with one of the bands, say, on the left. Rotate the prism-table, so that the band moves towards the centre. Keep the image in view, by turning the telescope, if necessary, in the direction of motion of the image. Turn the prism-table, till the

image reaches the position of minimum deviation and is about to retrace its path. Fix the prism-table. Adjust the position

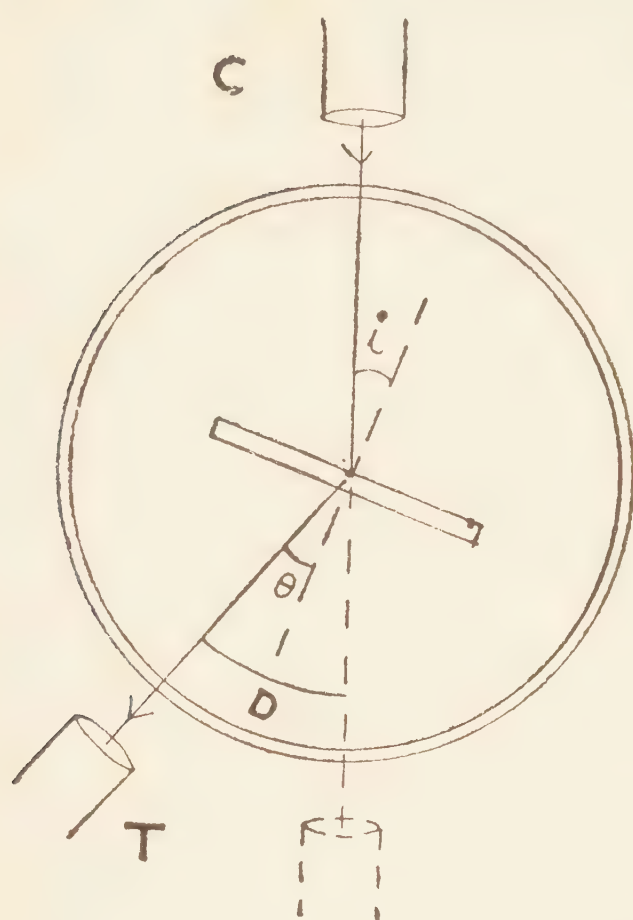


Fig. 138

of the telescope, so that the point of intersection of the cross-wires is in the middle of the band. Take the reading. Place the telescope in a line with the collimator and take the direct reading.

Repeat the experiment and take readings corresponding to the position of minimum deviation of the other bands in the 1st and the 2nd orders. After taking the reading in the minimum deviation position for each band, take the direct reading.

Turn the telescope to the right of the central band.

Repeat the experiment, adjusting the prism-table for the position of minimum deviation for each of the bands in the 1st and the 2nd orders. Take the direct reading, after taking the reading in the minimum deviation position for each band.

The difference between the direct reading and the reading in the position of minimum deviation for any band gives the angle of minimum deviation for the band.

[Taking the direct reading every time can be avoided, if the circular disc carrying the verniers is fixed, and the platform alone manipulated for adjusting for the position of minimum deviation. Then, the direct reading will be constant.]

If a parallel beam of light is incident on a grating and diffracted,

$$(\sin i + \sin \theta) = Nn\lambda$$

where i is the angle of incidence, θ the angle of diffraction, N the number of lines per cm. on the grating, n the order of the spectrum

and λ , the wavelength. i and θ are on the same side of the normal. In the position of minimum deviation, $i = \theta$. Let the angle of minimum deviation be D . Then,

$$(\sin i + \sin \theta) = 2 \sin \left(\frac{i + \theta}{2} \right) \cos \left(\frac{i - \theta}{2} \right)$$

When $i = \theta$, $(i - \theta) = 0$.

$$\therefore 2 \sin \frac{D}{2} = Nn\lambda, \text{ since } (i + \theta) = D$$

$$\therefore \lambda = \frac{2 \sin \frac{D}{2}}{Nn}.$$

From the known values of D , N and n , calculate the wavelength of each band.

Tabulate the results as follows :—

No. of lines per cm. on the grating =

Light used . —

I order.

Specifi- cation of line	Reading in Minimum Deviation Position		Direct Reading		Difference D		Wave-length $2 \sin \frac{D}{2}$ Nn
	Vernier A	Vernier B	Vernier A	Vernier B	Vernier A	Vernier B	
I Left							
II Right							

Have a similar tabular form for the II order.

Note :—The values of λ obtained by the normal incidence method will be accurate, only if (1) the adjustment of the prism-table for normal incidence is correct and (2) it is not disturbed during the later manipulations. As there are no such uncertainties in the minimum deviation method, it is more reliable.

EXPERIMENT 68

SPECTROMETER

FRAUNHOFER LINES—WAVE-LENGTHS

Aim :—To determine the wave-lengths of the Fraunhofer lines in the Solar Spectrum with a diffraction grating and a spectrometer.

Apparatus required:—Spectrometer, diffraction grating, plane mirror.

Procedure :—Adjust the eye-piece of the spectrometer, so that the cross-wires are distinctly seen. Adjust the telescope and collimator for parallel rays. Illuminate the slit of the collimator with sunlight reflected by the plane mirror.

Insert the grating in the holder, with the ruled surface facing the collimator. For levelling the table, so that the grating surface may be in a vertical plane, adopt the following method. Keep the telescope approximately perpendicular to the axis of the collimator. Turn the prism-table, till the image of the slit reflected from the surface of the mirror is seen in the telescope. The grating-holder is generally fitted parallel to the line joining two of the screws. Adjust one of the screws, till the image comes to the centre of the field of view. Rotate the prism-table, so that the surface of the grating is normal to the axis of the collimator. Move the telescope, so that it is in a line with collimator and the direct refracted image is seen in it. Adjust the third screw till the image comes to the centre. The prism-table is now horizontal and the surface of the grating vertical.

Set the surface of the grating normal to the axis of the collimator, adopting the method given in experiment 67. Fix the prism-table.

Adjust the plane mirror, so that the reflected beam of sunlight passes through the slit along the axis of the collimator and falls on the lens at the other end.

The diffraction pattern formed by the grating consists of a bright, undispersed centre with spectra on either side of it. The first two orders of spectra alone will be visible.

Move the telescope to one side of the centre, say, to the left, till the first order of spectra is seen in the field of view. The violet is nearest to the centre and the red farthest. Narrow the

slit till the vertical Fraunhofer's lines make their appearance. Identify the following lines — a, B, C in the red region, D_1 , D_2 , in the yellow, b_1 , b_2 , b_3 , E in the green, F in the blue and G, H_1 , H_2 in the violet.

Set the point of intersection of the cross-wires on each of the lines and take the readings.

Repeat the experiment with the 2nd order on the left, and the 1st and the 2nd orders on the right. Take the readings corresponding to each of the lines.

The difference in the readings for any particular line in a particular order, on the left and on the right divided by two gives the angle of diffraction.

If the angle of diffraction for any line is θ , then

$$\sin \theta = Nn\lambda$$

where N is the number of lines per cm. on the grating, n the order of the spectrum and λ , the wavelength of the line.

From the known values of θ , N , and n , calculate the wavelength of each line.

Tabulate the results as follows:—

Least count of the vernier =

Number of lines per cm. on the grating =

Specifi- cation of line.	Position I		Position II		Difference		Angle of diffraction	Wave-length
	Vernier A	Vernier B	Vernier A	Vernier B	Vernier A	Vernier B		
I Order of spec-tra.								
II Order of spec-tra.								

EXPERIMENT 69

POLARIMETER

Aim:—To determine the Specific Rotatory power of sugar, using a Laurents' Polarimeter.

Apparatus required :—Laurent's Polarimeter, sugar, cylindrical glass tubes of different lengths.

Description of apparatus :—The optical parts of a Laurent's Polarimeter consist essentially of a polariser and an analyser, mounted at either end of it, with their axes horizontal and along the same line. The polariser consists of a nicol. A convex lens fitted in front of it throws on it a parallel beam of light from a source placed at its principal focus. The polariser can be rotated about its axis. The analyser has another nicol. A low power telescope fitted behind it brings the parallel rays passing through it to a focus. The nicol can be rotated about its axis. A divided circle with verniers attached is fitted to it from which the angle of rotation can be measured.

When the two nicols are crossed, the field of view is dark. But, as it is difficult to judge when the field of view has maximum darkness, a special arrangement known as Laurent's half-wave plate or half-shade is fitted at the inner end of the polariser.

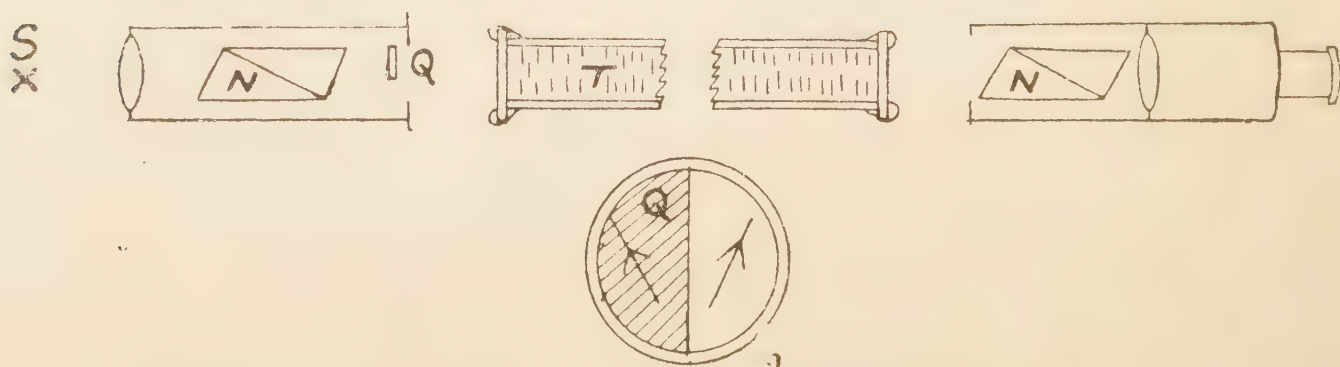


Fig. 139

It is a circular ring, with a thin quartz plate cut parallel to its optic axis covering one half of it and a glass plate absorbing light to an equal degree covering the other half. The thickness of the quartz plate is such that when polarised light passes through it, a path difference of half a wave-length is introduced between the ordinary and the extraordinary rays into which it is split up. So, on

emergence, they recombine to form plane polarised light but polarised in a different plane. The plane polarised beam of light from the polariser, passing through the glass plate, is unaffected. On the other hand, the beam passing through the quartz has its plane of polarisation rotated through an angle. These two beams, from the two halves of the ring, with different planes of polarisation, fall on the analyser. Hence, when the analyser is rotated, it can quench completely, only one-half of the field of view at a time. It is adjusted, so that the two halves of the field of view are equally dark. A slight rotation of the analyser in either direction, makes the two halves unequally dark. The position can be judged more or less very accurately.

In between the polariser and analyser, a cylindrical tube filled with solution can be mounted with its axis along the same line as those of the polariser and analyser.

Procedure :—Set up the sodium light in front of the polariser. at a distance approximately equal to the focal length of the lens in it. Look through the other end and adjust the telescope there, till the field of view is clear and well-defined. Weigh accurately 5 or 10 grams of sugar and dissolve it in 100 ccs. of distilled water.

Fill one of the cylindrical tubes with clear water and close the two ends with the circular discs provided. Mount it at the centre of the instrument coaxially with the polariser and the analyser. Look through the analyser. Rotate it till the two halves of the field are equally dark and the line of separation of the two vanishes. Take the reading.

Remove the tube, pour out the water and fill it with the prepared sugar solution of known concentration, say 5% or 10%. Place it in the same position as it occupied before. If you look through the analyser, the two halves of the field of view will appear unequally illuminated. Rotate the analyser, so that they are equally dark and the dividing line vanishes. Note the reading.

Repeat the experiment with a tube of a different length.

Let l be the length, in decimeters, of the column of solution in the tube and C , its concentration (expressed as a %). Then the angle of rotation of the plane of polarisation is given by

$$\theta = \rho \times l \times C$$

where ρ is the specific rotatory power.

$$\therefore \rho = \frac{\theta}{lC}.$$

Tabulate the readings as follows :—

Length between the circular discs in the glass tube = 17 cms.

Least count of the scale = 0.01°

Concen- tration of solution	Reading on the divided scale				Angle of rotation θ		Specific rotatory power p
	with water		with solution				
	Vernier A	Vernier B	Vernier A	Vernier B	Vernier A	Vernier B	
5%	51.71	51.64	57.03	56.97	5.32	6.33	62
10%	51.71	51.64	62.09	62.03	10.38	10.39	61

$\therefore$ Mean specific rotatory power = 61.5° .

SECTION VI

MAGNETISM

EXPERIMENT 70

DEFLECTION MAGNETOMETER

COMPARISON OF MAGNETIC MOMENTS

Aim :—To compare the magnetic moments of two magnets, using the deflection magnetometer.

Apparatus required :—Deflection magnetometer, two magnets, metre scale.

Description of apparatus :—The deflection magnetometer is a large compass box, made of brass and covered with glass at the top. On a pointed pivot, fixed at its centre at the bottom, rests

symmetrically a short magnetic needle on agate or ruby bearings. The magnetic needle can rotate freely in a horizontal plane, about its centre. A long, aluminium pointer is fixed at right angles to it at its mid-point. Its ends move over a circular scale, graduated in degrees. At the bottom of the box, a plane mirror is fitted in which the image of the aluminium pointer is visible. With the help of the image, the reading of the aluminium pointer on the scale can be read, without parallax error. When the magnetic needle is deflected, the aluminium pointer also is deflected. The deflection can be measured on the circular scale. The scale has two zeros, at the opposite ends of a diameter. The graduations are from 0° to 90° and then 90° to 0° . In the undeflected position, the box can be adjusted, so that the ends of the aluminium pointer read zero, zero. When the needle is deflected to the right or left, the deflection can be read off directly from the scale.

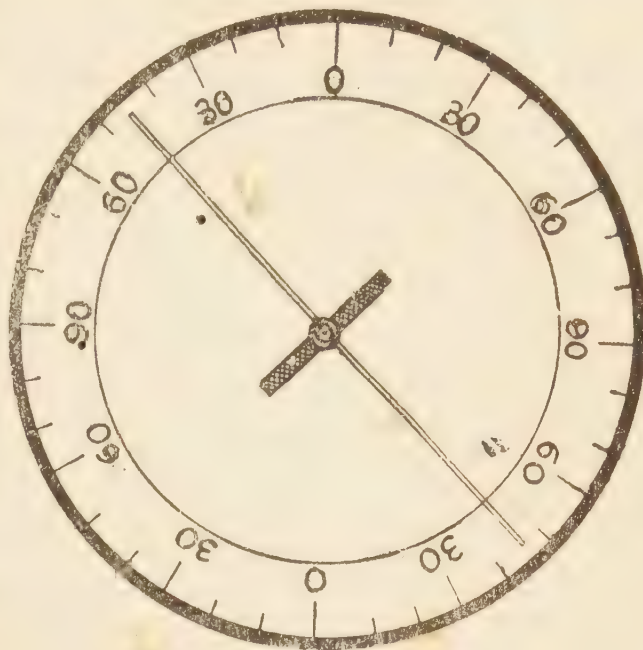


Fig. 140

The compass box is usually mounted at the centre of a long wooden board with a metre scale on it. The graduations on the scale start from its centre, the zero of the scale coinciding with the centre of the compass. But, for all practical purposes, with a compass box placed at the centre of a metre scale, the following experiments can be performed.

(A) Equal distance method

Procedure :—Place a metre scale on the table and set the compass box symmetrically at its centre. Adjust it, so that its centre coincides with the 50th cm. on the scale.

Tan A position of Gauss or End-on-position—Remove all magnets and magnetic substances to a distance. Slowly rotate the scale with the box on it, till the scale is parallel to the aluminium pointer. This means that the scale is perpendicular to the

magnetic meridian. Rotate the compass box alone about its centre, so that the ends of the aluminium pointer read zero, zero.

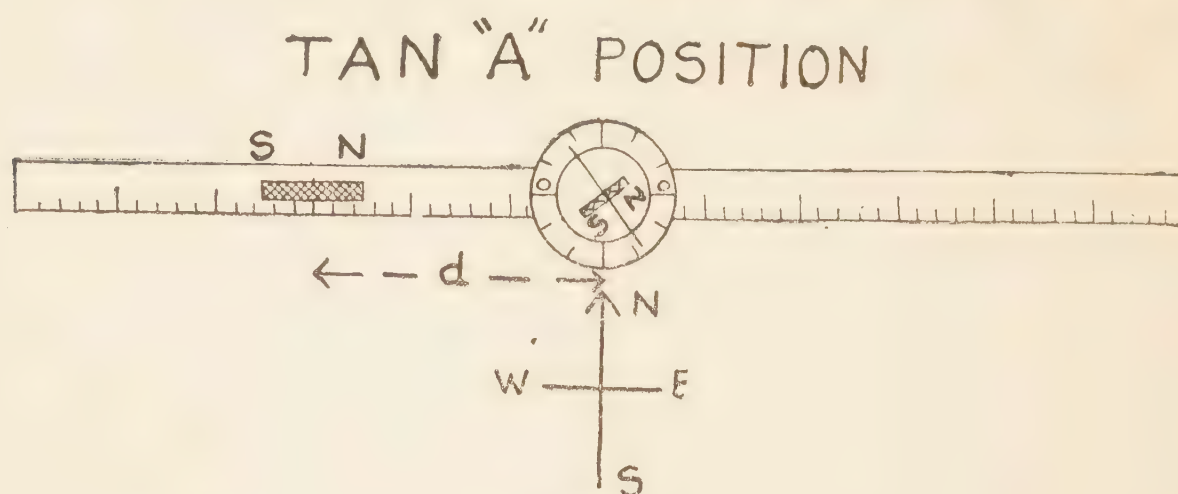


Fig.141

Place one of the magnets M_1 on the scale to the east or west of the compass box, so that the centre of the magnetic needle in the box lies on the axis of the magnet produced. This is the *Tan A position of Gauss or the End-on-position*. The magnetic needle is deflected and with it the aluminium pointer fixed to it. Read both ends of the pointer on the circular scales, without parallax error. Note down the deflections θ_1 and θ_2 . If the deflections are noted at both ends of the pointer and the average taken, any error due to the centre of the circular scale and the centre of the pointer not coinciding gets eliminated. The distance between the centre of the magnet and the centre of the needle must be such that the deflection lies between 40° and 50° . Note the distance d .

Reverse the magnet end for end, so that the other pole of the magnet is now nearer the compass box. Place it exactly in the same position as before. The needle is now deflected to the opposite side. Read both ends of the pointer and note down the deflections θ_3 and θ_4 . If the magnet is reversed and the deflections noted, any error due to the unsymmetrical magnetisation of the magnet gets eliminated.

Transfer the magnet to the other side of the compass box. Place it at the same distance from the centre of the box, with its axis produced passing through the centre of the magnetic needle. Note the deflections θ_5 and θ_6 of the two ends of the pointer. Transferring the magnet to the other side and noting the deflections will eliminate the error due to any displacement of the centre

of the scale. Reverse the magnet end for end and place it in the same position. Note the two deflections θ_7 and θ_8 . The average of all the eight deflections is taken as the deflection produced by the magnet for the particular distance d , in the Tan A position of Gauss.

Alter the distance between the centre of the magnet and the centre of the magnetic needle and repeat the experiment. Take sets of readings for two or three distances.

Remove the magnet. Place the second magnet on the scale at the same distances from the magnetic needle and repeat the experiment for each distance.

The magnetic intensity F , at any point on the axis of a magnet, is given by the formula,

$$F = \frac{2Md}{(d^2 - l^2)^2}$$

where M is the magnetic moment of the magnet, $2l$ its length and d the distance of the point from the centre of the magnet.

Let the two magnets whose moments are to be compared be M_1 and M_2 . Then, for the same distance d ,

$$F_1 = \frac{2M_1d}{(d^2 - l_1^2)^2}$$

$$\text{and } F_2 = \frac{2M_2d}{(d^2 - l_2^2)^2}$$

where $2l_1$ and $2l_2$ are the respective lengths of the magnets M_1 and M_2 . Now,

$$F_1 = H \tan a$$

$$\text{and } F_2 = H \tan b$$

where a and b are the respective mean deflections of the magnetic needle for the distance d and H is the horizontal component of the earth's field at the place.

$$\therefore \frac{H \tan a}{H \tan b} = \frac{\frac{2M_1d}{(d^2 - l_1^2)^2}}{\frac{2M_2d}{(d^2 - l_2^2)^2}}$$

$$\therefore \frac{M_1}{M_2} = \frac{(d^2 - l_1^2)^2}{(d^2 - l_2^2)^2} \times \frac{\tan a}{\tan b}$$

Tabulate the readings as follows :—

I. Tangent A position of Gauss.

Distance from centre of needle to centre of magnet	Magnet east of needle				Magnet west of needle				Mean deflection θ	Tan θ
	North pole facing East		North pole facing West		North pole facing East		North pole facing West			
	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8		
	Magnet — M_1									
	Mag net — M_2									

II. Length of Magnet $M_1 = 2l_1$

Length of Magnet $M_2 = 2l_2$

Distance from centre of magnet to centre of needle	Tan mean deflection		$\frac{M_1}{M_2} = \frac{(d^2 - l_1^2)^2}{(d^2 - l_2^2)^2} \times \frac{\tan a}{\tan b}$
	for Magnet M_1 Tan a	for Magnet M_2 Tan b	

$\therefore$ Mean ratio of the magnetic moments $\frac{M_1}{M_2} =$

Tan B position of Gauss or Broadside-on-position.

Procedure :—Remove all magnets and magnetic substances to a distance. Rotate the scale, so that it is perpendicular to the aluminium pointer and parallel to the magnetic needle. Rotate the box alone, till the aluminium pointer reads zero, zero. Place the magnet on the scale with its axis perpendicular to it, and the centre of the magnetic needle on the perpendicular bisector

of the magnet. This is the *Tan B position* or the *Broadside on position*.

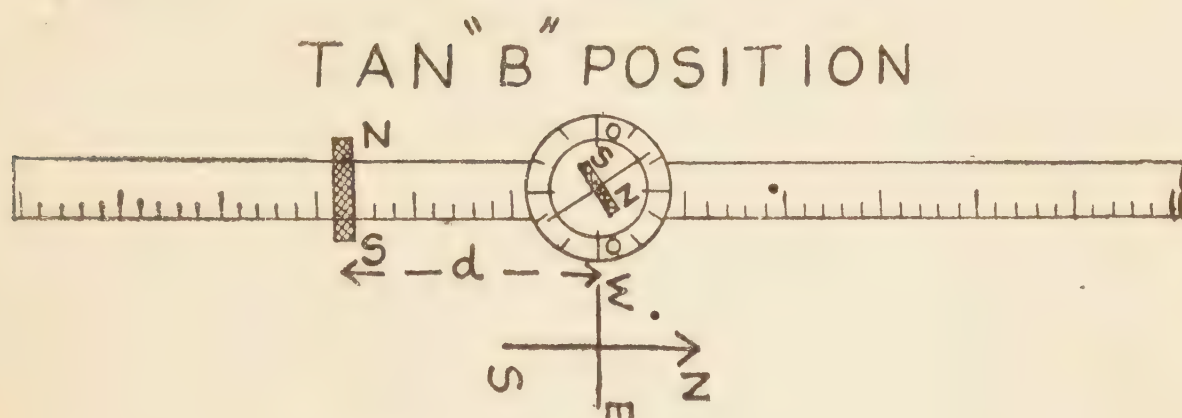


Fig. 142

The needle is deflected. The distance between the centre of the magnet and the centre of the magnetic needle must be such that the deflection is from 40° to 50° . Note the distance d . Read both ends of the pointer and note down the deflections θ_1 & θ_2 . Reverse the magnet end for end and keeping it at the same distance d , read the deflections θ_3 & θ_4 . Transfer the magnet to the opposite side. Place it at the same distance d from the centre of the needle and note the deflections θ_5 & θ_6 . Reverse it end for end. Keep it at the same distance d and note the deflections θ_7 & θ_8 . The average of the eight deflections is the mean deflection produced by the magnet in the broadside-on-position for the particular distance.

Alter the distance. Repeat the experiment. Take readings for two or three distances.

Replace the magnet by the second one. Repeat the experiment and note down the deflections for the same distances.

The magnetic intensity F at any point on the perpendicular bisector of a magnet is given by,

$$F = \frac{M}{(d^2 + l^2)^{3/2}}$$

So, for distance d , for the two magnets M_1 and M_2 ,

$$F_1 = \frac{M_1}{(d^2 + l_1^2)^{3/2}}$$

$$\text{and } F_2 = \frac{M_2}{(d^2 + l_2^2)^{3/2}}$$

Now, $F_1 = H \tan a$
 and $F_2 = H \tan b$

where a and b are the respective mean deflections produced.

$$\therefore \frac{H \tan a}{H \tan b} = \frac{\frac{M_1}{(d^2 + l_1^2)^{3/2}}}{\frac{M_2}{(d^2 + l_2^2)^{3/2}}}$$

$$\therefore \frac{M_1}{M_2} = \frac{(d^2 + l_1^2)^{3/2}}{(d^2 + l_2^2)^{3/2}} \times \frac{\tan a}{\tan b}$$

Tabulate the readings as follows:—

I Tangent B position of Gauss

Distance between centre of magnet and centre of needle	Magnet North of needle				Magnet South of needle				Mean deflec- tion θ	Tan θ
	North pole facing East		North pole facing West		North pole facing East		North pole facing West			
	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8		
Mag net— M_1										
Mag net— M_2										

II. Length of magnet $M_1 = 2 l_1$

Length of magnet $M_2 = 2 l_2$

Distance from centre of magnet to centre of needle	Tan mean deflection for		$\frac{M_1}{M_2} = \frac{(d^2 + l_1^2)^{3/2}}{(d^2 + l_2^2)^{3/2}} \times \frac{\tan a}{\tan b}$
	Magnet M_1 Tan a	Magnet M_2 Tan b	

$\therefore$ Mean ratio of the magnetic moments $\frac{M_1}{M_2} =$

(B) Equal deflection method
(Null method)

Procedure :—Tan A position. Remove all magnets and magnetic substances to a distance and adjust the scale and compass box for the Tan A position. The scale will be parallel to the aluminium pointer.

Place the magnet M_1 on the scale on one side of the compass box, in the Tan A position. Adjust its distance, so that the deflection is between 40° and 50° . Let the distance between the centre of the magnet and the centre of the needle be d_1 . Place the

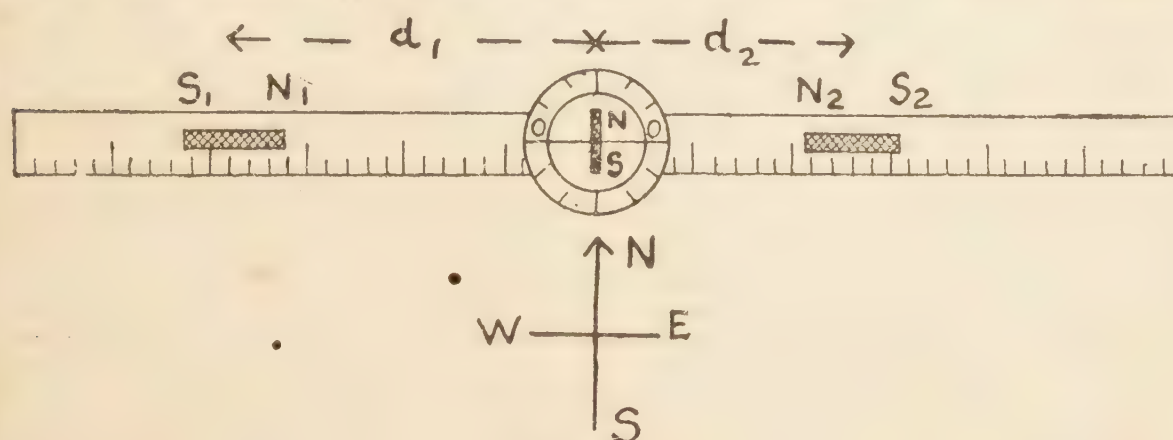


Fig. 143

other magnet M_2 on the scale on the other side, so that similar poles face each other. Adjust it, so that the deflections produced by the magnets are equal and opposite and the aluminium pointer, reads zero, zero. Note the distance d_2' from the centre of magnet M_2 to the centre of the magnetic needle. Reverse the two magnets end for end. Keeping the first magnet M_1 at the same distance d_1 , adjust the second magnet M_2 , so that the deflection is zero. Note the distance d_2'' between the centres of the magnet M_2 and the magnetic needle.

Interchange the magnets. Keep the magnet M_1 at the same distance d_1 from the centre of the needle. Adjust the distance of the magnet M_2 so that the deflection is zero. Measure the distance d_2''' of the second magnet. Reverse the magnets. Keep the magnet M_1 at the same distance d_1 . Adjust the position of the second magnet M_2 , so that the deflection is zero. Measure the distance d_2'''' of the second magnet M_2 , from the centre of the needle. Take the average of d_2' , d_2'' , d_2''' and d_2'''' . Let it be d_2 .

Alter the distance d_1 between the centres of the first magnet M_1 and the magnetic needle and repeat the experiment. Find the average value of d_2 for the second magnet, for null deflection. Take two or three sets of readings.

Now, since the deflection is zero, the magnetic intensities at the centre of the magnetic needle are equal and opposite. So,

$$\frac{2 M_1 d_1}{(d_1^2 - l_1^2)^2} = \frac{2 M_2 d_2}{(d_2^2 - l_2^2)^2}$$

$$\therefore \frac{M_1}{M_2} = \frac{(d_1^2 - l_1^2) \times d_2}{(d_2^2 - l_2^2) \times d_1}$$

Tabulate the readings as follows :—

Tan A Position.

Length of magnet $M_1 = 2l_1$ cms.

Length of magnet $M_2 = 2l_2$ cms.

Distance of magnet M_1 from centre of needle d_1	Distance of magnet M_2 from centre of needle					$\frac{M_1}{M_2} = \frac{(d_1^2 - l_1^2)d_2}{(d_2^2 - l_2^2)d_1}$
	d_2'	d_2''	d_2'''	d_2''''	Average d_2	

$$\therefore \text{Average } \frac{M_1}{M_2} =$$

Tan B Position :—Remove all magnets to a distance and adjust the scale and compass-box for the Tan B position. The scale will be perpendicular to the aluminium pointer.

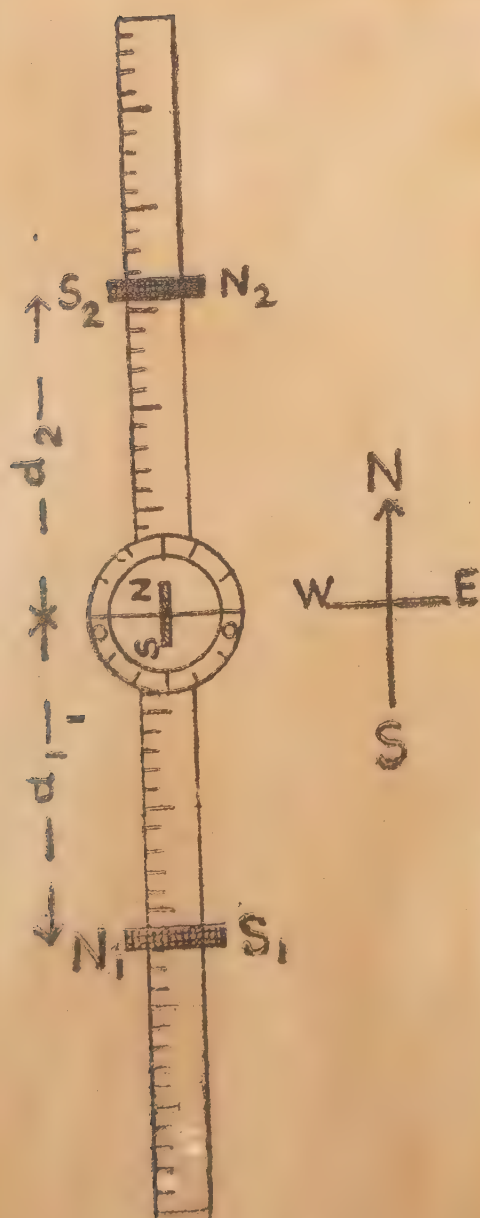


Fig. 144

Place magnet M_1 on the scale, north or south of the compass, with its axis parallel to the aluminium pointer and with the centre of the magnetic needle on its perpendicular bisector. Adjust it, so that the deflection is from 40° to 50° . Note the distance of the magnet from the centre of the needle. Let it be d_1 . Place magnet M_2 on the scale, on the other side of the box, so that similar poles point in opposite directions. Adjust it, so that the resultant deflection is zero. Measure the distance

between the centre of M_2 and the centre of the needle. Let it be d_2' . Reverse the magnets end for end. Keeping M_1 at the same distance d_1 from the centre of the needle, adjust M_2 so that the deflection is zero. Measure d_2'' , the distance between the centre of the magnet and the centre of the needle. Inter-change the magnets. Keep magnet M_1 at the same distance d_1 from the centre of the needle. Adjust magnet M_2 , so that the deflection is zero. Measure d_2''' its distance from the centre of the magnetic needle. Reverse the magnets end for end. Keep magnet M_1 at the same distance d_1 . Adjust magnet M_2 , so that the deflection is zero. Measure d_2'''' its distance from the centre of the magnetic needle. Let d_2 be the average of d_2' , d_2'' , d_2''' and d_2'''' .

Alter the distance d_1 between the centres of the magnet M_1 and the magnetic needle and repeat the experiment. Find the average value of d_2 , for null deflection. Take two or three sets of readings.

Now, since the deflection is zero, the magnetic intensities due to the magnets at the centre of the magnetic needle are equal and opposite. So,

$$\frac{M_1}{(d_1^2 + l_1^2)^{3/2}} = \frac{M_2}{(d_2^2 + l_2^2)^{3/2}}$$

$$\therefore \frac{M_1}{M_2} = \frac{(d_1^2 + l_1^2)^{3/2}}{(d_2^2 + l_2^2)^{3/2}}$$

Tabulate the readings as follows :—

Tan B position

Length of magnet $M_1 = 2l_1$ cms.

Length of magnet $M_2 = 2l_2$ cms.

Distance between centres of magnet M_1 and magnetic needle d_1	Distance between centre of magnet M_2 and centre of needle					$\frac{M_1}{M_2} = \frac{(d_1^2 + l_1^2)^{3/2}}{(d_2^2 + l_2^2)^{3/2}}$
	d_2'	d_2''	d_2'''	d_2''''	Average d_2	

$$\therefore \text{Average } \frac{M_1}{M_2} =$$

Method	Ratio of $\frac{M_1}{M_2}$		Mean
	Tan A position	Tan B position	
Equal distance			
Equal or null deflection			

$$\therefore \text{Mean value of } \frac{M_1}{M_2} =$$

EXPERIMENT 71

DEFLECTION MAGNETOMETER

DETERMINATION OF M AND H

Aim :—To determine (1) the magnetic moment of a magnet and (2) the horizontal component of the earth's magnetic intensity at a place.

Apparatus required :—Deflection magnetometer, magnet, vibration jar.

Procedure :—Tan A position of Gauss. Remove all magnets and magnetic substances to a distance. Place a metre scale on the table. Place at the middle of the scale, a deflection magnetometer (compass box). Adjust it, so that its centre coincides with the 50 cm. on the scale.

Slowly rotate the scale with the compass box, so that the scale is parallel to the aluminium pointer. Rotate the compass box alone, till the aluminium pointer reads zero, zero. Avoid parallax error whenever you take a reading by keeping the eye vertically above the pointer, so that it hides its own image.

Place the magnet on the scale on one side of the compass (east or west of it). Adjust it, so that its axis is parallel to the scale and passes through the centre of the magnetic needle. The magnetic needle and the aluminium pointer are deflected

Move the magnet along the scale till the deflection is about 40° to 50° . Read the deflections at both ends of the aluminium pointer. Let them be θ_1 and θ_2 . Note the distance d from the centre of the magnet to the centre of the needle.

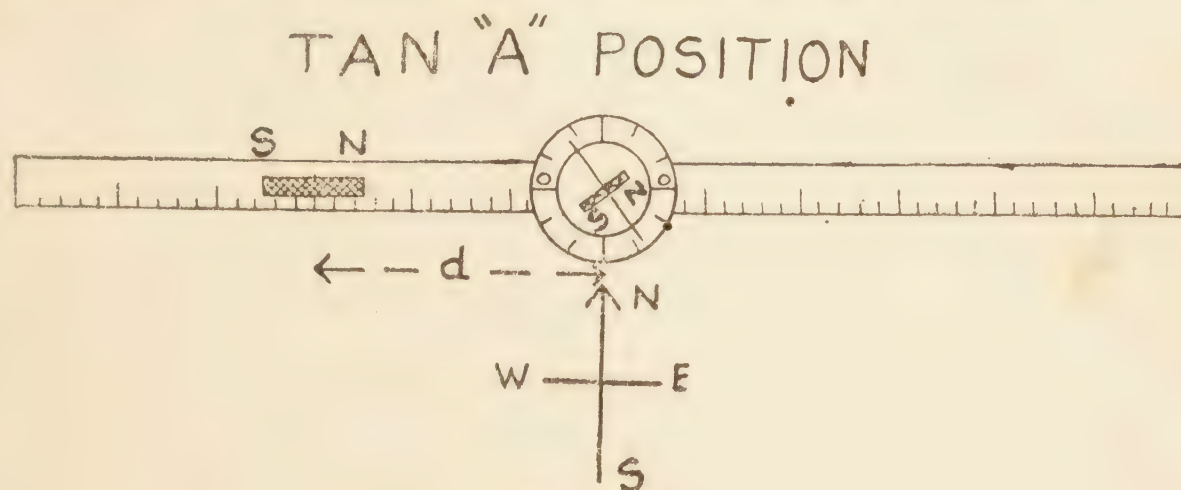


Fig. 145

Reverse the magnet end for end. Keep the magnet at the same distance d . The deflections also will be reversed. Note them. Let them θ_3 and θ_4 .

Transfer the magnet to the other side of the compass box. Place it at the same distance d from the centre of the compass box. Note the deflections θ_5 and θ_6 , of the two ends of the aluminium pointer. Reverse the magnet end for end. Keep the magnet at the same distance d and note the deflections θ_7 and θ_8 . Take the average of the eight deflections. That will give the mean deflection of the magnetic needle due to the magnet, when the distance between their centres is d , in the Tan A position.

Repeat the experiment for two more distances. Remember that the deflections should not be more than 55° or less than 35° .

The magnetic intensity F at any point on the axis of a magnet of moment M is given by,

$$F = \frac{2 M d}{(d^2 - l^2)^2}$$

where d is the distance of the point from the centre of the magnet and $2l$ is its length.

If the axis of the magnet is perpendicular to the magnetic meridian, a short magnetic needle placed at the point will be deflected through an angle θ , such that

$$F = H \tan \theta$$

where H is the horizontal component of the Earth's magnetic intensity at the place,

$$\therefore \frac{2 M d}{(d^2 - l^2)^2} = H \tan \theta.$$

$$\therefore \frac{M}{H} = \frac{(d^2 - l^2)^2}{2 d} \tan \theta.$$

Since $\frac{M}{H}$ is a constant, $\frac{(d^2 - l^2)^2 \tan \theta}{2 d}$ will be constant.

Tan B position :—Remove the magnet to a distance. Adjust the scale and the compass box on it, for the Tan B position. The aluminium pointer will be perpendicular to the scale.

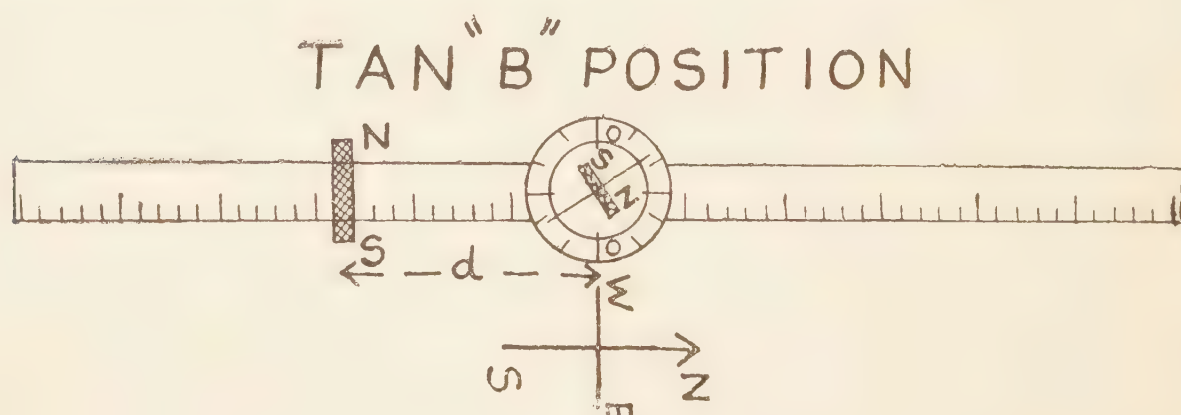


Fig. 146

Place the magnet on the scale on one side of the compass box (north or south of it). Adjust it, so that its axis is perpendicular to the scale and the centre of the magnetic needle lies on its perpendicular bisector. Move it, so that the deflection of the aluminium pointer is about 40° to 50° . Read the deflections θ_1 and θ_2 , of the aluminium pointer. Note the distance d between centre of the magnet and the centre of the magnetic needle.

Reverse the magnet end for end. Place it at the same distance d and note the deflections θ_3 and θ_4 .

Transfer the magnet to the other side of the compass box. Place it at the same distance d from the centre of the magnetic needle. Read the deflections θ_5 and θ_6 .

Reverse the magnet end for end. Keep it at the same distance d . Read the deflections θ_7 and θ_8 . Take the average of the eight deflections.

Repeat the experiment for two more distances of the magnet, from the centre of the magnetic needle. See that the deflections are not more than 55° nor less than 35° .

The magnetic intensity F at any point on the perpendicular bisector of a magnet is given by,

$$F = \frac{M}{(d^2 + l^2)^{3/2}} \quad .$$

If the axis of the magnet is perpendicular to the magnetic meridian, a magnetic needle placed at the point is deflected through an angle θ , such that

$$F = H \tan \theta.$$

$$\therefore \frac{M}{(d^2 + l^2)^{3/2}} = H \tan \theta$$

$$\therefore \frac{M}{H} = (d^2 + l^2)^{3/2} \tan \theta$$

Since $\frac{M}{H}$ is constant, $(d^2 + l^2)^{3/2} \tan \theta$ will be constant.

Period of oscillation of the magnet in the earth's field.

The period of oscillation of the magnet is determined by using the vibration jar. It is a tall cylindrical glass jar. A brass stirrup is suspended inside, by a long torsionless silk fibre. The magnet can rest in the stirrup with its axis horizontal. The glass jar prevents air currents from disturbing the oscillations of the magnet.

To start with, a piece of brass of the same dimensions as the magnet is placed in the stirrup. If there is any torsion in the fibre, it will be removed by the fibre untwisting itself, when the brass piece is placed in the stirrup. Replace the brass by the magnet. Allow it to come to rest. Make a mark to indicate its equilibrium position. Bring another magnet near it and set it in vibration. The amplitude of oscillation must not be large. When the axis of the magnet passes across the equilibrium position, start the stop-clock. Find the time of 10 or 15 oscillations. Repeat the experiment and take three readings. From the readings find the mean period of oscillation T .

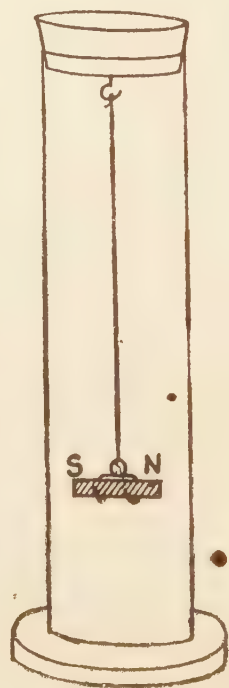


Fig. 147

II. Tan B Position

Distance from centre of magnet to centre of needle	Magnet North of compass box				Magnet South of compass box				Average θ	Tan θ	$\frac{M}{H} = (d^2 + l^2)^{3/2} \times \tan \theta$
	N. Pole pointing E		N. Pole pointing W		N. Pole pointing E		N. Pole pointing W				
	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8			

Mean value of $\frac{M}{H} =$

III. Period of oscillation of magnet

Time for 25 oscillations	Period of oscillation T

IV. Mass of magnet = W grams.

(Give particulars of weighing)

Length of magnet = a cms.

Breadth of magnet = b cms.

(Give particulars of measurement, using vernier calipers.)

$$I = W \left(\frac{a^2 + b^2}{12} \right)$$

[if the magnet used, is a rectangular bar magnet.]

$$MH = \frac{4\pi^2 I}{T^2}$$

Using the mean values of $\frac{M}{H}$ and MH, calculate M and H from

$$M = \sqrt{MH \times \frac{M}{H}}$$

$$\text{and } H = \sqrt{\frac{MH}{\frac{M}{H}}}$$

$\therefore$ The magnetic Moment of the Magnet = cgs units.

The Horizontal component of the Earth's field

= gauss.

LAW OF INVERSE SQUARES

The Law of Inverse Squares can be verified from the readings taken, if the magnet used is short and powerful. The deflections can be noted for large values of the distance d.

The formula $\frac{2Md}{(d^2 - l^2)^2}$ can be written as $\frac{2M}{d^3}$ and $\frac{M}{(d^2 + l^2)^{3/2}}$ as $\frac{M}{d^3}$, when $\frac{l}{d}$ is very small. Then,

$\frac{2M}{d^3} = H \tan \theta_A$ (for Tan " A " Position)

and $\frac{M}{d^3} = H \tan \theta_B$ (for Tan " B " Position)

$\therefore \frac{\tan \theta_A}{\tan \theta_B} = 2$, when d is the same.

Thus, if this relationship is verified, then it follows that *the magnetic intensity at any point on the axis of a magnet is twice the intensity at a point at same distance, on the perpendicular bisector.* Hence, the Inverse Square Law which is used for deriving the respective magnetic intensities is verified.

Tabulate the results as follows :—

Distance from centre of magnet to centre of needle	Tan of mean deflection		$\frac{\tan \theta_A}{\tan \theta_B}$
	in Tan " A " Position	in Tan " B " Position	
	Tan θ_A	Tan θ_B	

EXPERIMENT 72

DEFLECTION MAGNETOMETER

POLE-STRENGTH OF MAGNET AND VERIFICATION OF INVERSE SQUARE LAW

Aim :—(1) To determine the pole-strength of a long magnet and to verify the Inverse Square Law and (2) to determine the pole-strength of a short magnet, using the Deflection Magnetometer.

Apparatus required :—Deflection Magnetometer, long magnet, short magnet, vibration box.

(A) Long magnet

Procedure :—A Robison's magnet is suitable for this experiment. It is made up of a thin steel rod with spherical balls at either end. When it is magnetised, the poles are situated exactly at the centres of the spheres. Hence, the magnet has point poles. In the absence of a Robison's magnet, any long magnet (30 to 40 cms. long) can be used.

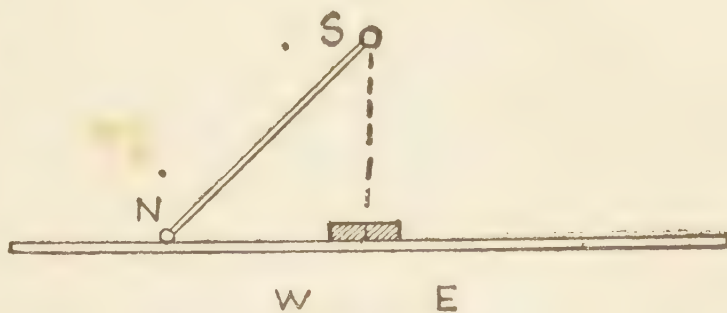


Fig. 148

Tan A position :—Remove all magnets [to a distance. Adjust the deflection magnetometer for the Tan A position, with the scale parallel to the aluminium pointer.

Place the long magnet on the scale on one side (due east or west) of the compass box, with one of its ends resting on the scale. The line joining the pole and the centre of the magnetic needle must be perpendicular to the magnetic meridian. The other end is adjusted to be vertically above the centre of the magnetic needle. Hence, the pole at this end will not produce any horizontal force on the poles of the needle. Only the pole at the end that rests on the scale acts on the needle. Adjust it, so that the deflection is about 40° to 50° . Note the distance d of the pole from the centre of magnetic needle. Read the deflections θ_1 and θ_2 at the two ends of the pointer.

Transfer the magnet to the other side and place the same end on the scale at the same distance d from the centre of the magnetic needle. Note the deflections θ_3 and θ_4 . Find the average of the four deflections.

Repeat the experiment with the other pole. See that, when one of the poles is on a level with the axis of the magnetic needle, the other pole is vertically above the centre of the needle. Note the four deflections for the distance d as before. Find their average.

Alter the distance from the centre of the needle and repeat the experiment for two or three more distances. The deflections must not be greater than 55° or less than 35°.

The magnetic intensity F at a distance d from a pole of strength m is $\frac{m}{d^2}$. This follows directly from the Inverse Square Law.

If this intensity F is perpendicular to the magnetic meridian and a magnetic needle is placed at that point, then it will be deflected through an angle θ such that,

$$F = H \tan \theta.$$
$$\therefore \frac{m}{d^2} = H \tan \theta.$$
$$\therefore \frac{m}{H} = d^2 \tan \theta.$$

Since $\frac{m}{H}$ is a constant, $d^2 \tan \theta$ will be constant. If $d^2 \tan \theta$ is found to be constant, the Inverse Square Law gets verified.

Again, if H is known, m can be calculated.

$$m = H \times d^2 \tan \theta.$$

Tabulate the readings as follows :—

I. North pole of magnet on a level with the needle and the south pole vertically above its centre.

Distance between pole and centre of needle d	North pole east of needle		North pole west of needle		Average θ	Tan θ	$d^2 \tan \theta$
	θ_1	θ_2	θ_3	θ_4			

II. South pole of magnet on a level with the needle and north pole vertically above centre of needle.

Distance between pole and centre of needle	South pole east of needle		South pole west of needle		Average θ	Tan θ	$d^2 \tan \theta$
	θ_1	θ_2	θ_3	θ_4			

III. H	=	gauss.	
Mean value of $d^2 \tan \theta$	=		
$\therefore$ Strength of North pole	=		
and strength of South pole	=		

(B) Short magnet .

Procedure :—The magnet supplied may be cylindrical or rectangular.

Tan A position :—Remove all magnets to a distance. Adjust the magnetometer for Tan A position, with the scale parallel to the aluminium pointer.

Place the magnet vertically on the scale on one side (east or west) of the compass box, with one end resting on the scale, on a level with the magnetic needle. The line joining the pole at that end and the centre of the needle must be perpendicular to the magnetic meridian. Adjust its distance, so that the deflection is from 40° to 50° . Note the distance d from the pole to the centre of the needle and the deflections θ_1 and θ_2 , at the two ends of the pointer.

Transfer the magnet to the other side. Place the same pole at the same distance d from the centre of the needle. Note the deflections θ_3 and θ_4 , at the two ends of the pointer.

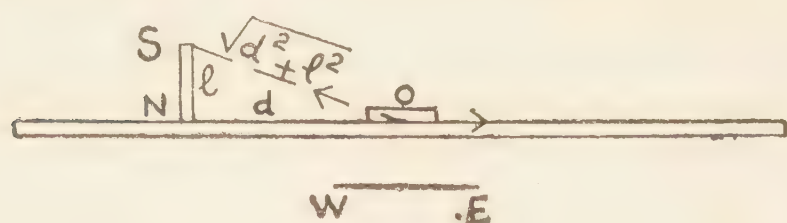
Repeat the experiment, with the other pole resting on the scale. Keep it at the same distance d . Find the four deflections. Let them be θ_5 , θ_6 , θ_7 and θ_8 . Find the average of the eight deflections.

Alter the distance and repeat the experiment for two or three more distances. See that the deflections are not more than 55° or less than 35° .

Remove the torsion in the suspension fibre of the vibration box, by keeping a brass rod similar to the magnet on the stirrup. Replace it by the magnet. Set it in vibration. Find the time for 10 or 15 oscillations twice or thrice. Find the mean period of oscillation T .

Find the mass W of the magnet accurately. Measure its length l and breadth b with a vernier calipers.

The magnetic intensity due to the magnet at the centre of the magnetic needle is made up of,



. 149

(1) a force equal to $\frac{m}{d^2}$ due to the pole resting on the scale, along the horizontal.

(2) the component of the force due to the other pole, along the horizontal, but in the opposite direction, equal to

$$\frac{m}{(d^2 + l^2)} \times \frac{d}{(d^2 + l^2)^{\frac{3}{2}}} = \frac{m d}{(d^2 + l^2)^{\frac{3}{2}}}$$

So, the resultant intensity F is equal to

$$\frac{m}{d^2} - \frac{m d}{(d^2 + l^2)^{\frac{3}{2}}}$$

If this force is perpendicular to the magnetic meridian, it will produce a deflection θ of the needle such that

$$F = H \tan \theta.$$

$$\therefore \frac{m}{d^2} - \frac{m d}{(d^2 + l^2)^{\frac{3}{2}}} = H \tan \theta.$$

$$\therefore \frac{m}{H} = \frac{\tan \theta}{\frac{1}{d^2} - \frac{d}{(d^2 + l^2)^{\frac{3}{2}}}}$$

From the known values of θ , d and l , $\frac{m}{H}$ can be calculated. If H is known, m can be calculated.

Now, if T is the period of oscillation of the magnet in the earth's field, then

$$T = 2\pi \sqrt{\frac{I}{MH}}.$$

where I is the moment of inertia of the magnet about an axis passing through its centre and perpendicular to its length.

$$\therefore MH = \frac{4\pi^2 I}{T^2}$$

$$\text{and } mH = \frac{4\pi^2 I}{T^2 l}, \text{ since } M = m \times l.$$

Again, $m H \times \frac{m}{H} = m^2$ and $\frac{m H}{\frac{m}{H}} = H^2$

$\therefore m = \sqrt{m H \times \frac{m}{H}}$

and $H = \sqrt{\frac{m H}{\frac{m}{H}}}$

Tabulate the results as follows:—

I.

Distance of pole from centre of needle	North pole on scale •				South pole on scale				Average θ	Tan θ	$\frac{\tan \theta}{\frac{1}{d^2} - \frac{d}{(d^2 + l^2)^{3/2}}}$
	• East of needle		West of needle		East of needle		West of needle				
	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8			
											$\frac{m}{H}$

$\therefore$ Mean value of $\frac{m}{H} =$

II.

Time for 20 oscillations	Period of oscillation
--------------------------	-----------------------

$\therefore$ Mean period of oscillation = T secs.

III. Mass of magnet = W grams
(using a balance)

Length of magnet = l cms.

Breadth of magnet = b cms.
(using vernier calipers)

Moment of Inertia I of magnet = $W \times \frac{(l^2 + b^2)}{12}$
(assuming that it is rectangular).

$$m H = \frac{4\pi^2 I}{T^2 l}$$

$$\therefore m = \sqrt{mH \times \frac{m}{H}}$$

$$\text{and } H = \sqrt{\frac{mH}{m}}$$

$\therefore$ The pole strength of the magnet =
and the Horizontal component of }
the Earth's field =

EXPERIMENT 73.

VIBRATION MAGNETOMETER

Aim :—(1) To compare the intensities of different magnetic fields (2) to verify the Inverse Square Law and (3) to determine the polestrength, using a vibration magnetometer.

Apparatus required :—Vibration magnetometer, long magnet, stop-watch.

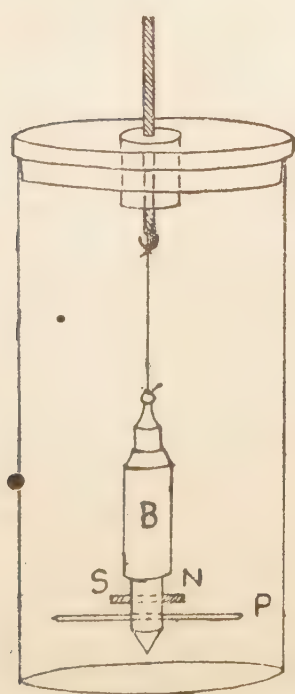


Fig. 150

Description of apparatus :—One of the common types of vibration magnetometer is the Searle's type. It consists of a cylindrical brass holder B. A short magnetic needle NS, is inserted into it at its lower end perpendicular to the axis of the holder. Below the magnetic needle and parallel to it, a long brass pointer P is inserted into the holder. The holder is suspended by unspun silk fibre, inside a cylindrical glass jar. The mouth of the jar is covered by a wooden disc. A thin brass rod passes through the centre of the disc and from a hook at the end of this rod the silk fibre is suspended. The rod can be raised or lowered

for adjusting the height of the magnetometer above the bottom of the jar.

(A) Comparison of magnetic fields

Procedure :—With the help of a small compass needle, draw a line on the table to indicate the magnetic meridian and place the vibration magnetometer on the line. Remove all magnets and magnetic substances to a distance. If the silk fibre is free from torsion, the magnet will come to rest along the magnetic meridian and the brass pointer will indicate the magnetic meridian. The magnetometer usually oscillates without coming to rest quickly. In that case, lower the central rod till the magnetometer touches the bottom of the vessel and comes to rest. Then, gently and slowly raise the rod.

Slowly bring a second magnet near the needle, set it in vibration through a small arc and withdraw it. Omit the first few oscillations. When the needle passes across the equilibrium position, start the stop-watch. Find the time for 20 to 30 oscillations. Take two or three readings. From the mean time taken, calculate the period of oscillation.

Take the magnetometer to different places in the laboratory. At each place, repeat the experiment, and find the period of oscillation.

Let T be the period of oscillation at a place where the magnetic intensity is H . Let I be the moment of inertia of the vibrating system and M the magnetic moment of the needle. Then,

$$T = 2\pi \sqrt{\frac{I}{MH}}$$

$$\therefore T^2 = \frac{4\pi^2 I}{MH} = \frac{K}{H}$$

where $\frac{4\pi^2 I}{M} = K$, a constant for the vibrating system.

$$\therefore T^2 \propto \frac{1}{H}.$$

If n is the frequency of oscillation,

$$\therefore T = \frac{1}{n} \quad \text{or} \quad T^2 = \frac{1}{n^2}$$

$$\therefore \frac{1}{n^2} \propto \frac{1}{H} \quad \text{or} \quad n^2 \propto H.$$

If H_1, H_2, H_3 , etc. are the magnetic intensities at various places and n_1, n_2, n_3 , etc., the corresponding frequencies of oscillation at the places,

$$H_1 : H_2 : H_3, \text{ etc.} = n_1^2 : n_2^2 : n_3^2 \text{ etc.}$$

Tabulate the readings as follows :—

Place	Time for 25 oscillations				Period of oscillation T	Frequency of oscillation $n = \frac{1}{T}$	n^2
	1	2	3	Mean			

Taking the intensity at any one place as the standard, find the ratios of,

$$\frac{n_2^2}{n_1^2}, \frac{n_3^2}{n_1^2}, \frac{n_4^2}{n_1^2}, \text{ etc.}$$

(B) Verification of Inverse Square Law

Procedure :—A fairly long magnet must be used for this experiment. A long Robison's magnet will be quite suitable.

Remove all magnets and magnetic substances to a distance. Draw a line on the table to indicate the magnetic meridian. Place the vibration magnetometer on this line. Allow the vibrating system to come to rest. If the suspension is torsionless, the needle will come to rest, parallel to the magnetic meridian. See, if the pointer is vertically above the line drawn on the table.

Set the needle to vibrate through a small angle, by slowly bringing a magnet near and withdrawing it. Find the time for 20 to 30 oscillations. Take three readings and from the mean time, calculate the period.

- Place the North pole of the long magnet on the line, due South of the needle, at a distance of 10 cms. from the centre of the needle. The pole must be on the same horizontal line as the needle. Slant the magnet, so that its other end is vertically above the centre of the needle. Clamp the magnet in this position using a wooden bunsen stand. Set the needle to vibrate. Find the time of 20 to 30 oscillations. Take three readings and calculate the mean period of oscillation.

Move the pole to a distance of 15 cms., 20 cms., and 25 cms., from the centre of the needle. Keep the other pole vertically above the centre of the needle. For each position, find the mean period of oscillation, as mentioned above. [If there should be an appreciable difference in the period, as the pole is taken farther and farther away, the pole must be strong.]

Place the South pole of the long magnet, due North of the needle at the same distance, keeping the other pole, always above the centre of the needle. In each position, find the mean period of oscillation as mentioned above.

Let the magnetic intensity due to the Earth's field alone at the centre of the needle be H . When the North pole of a magnet is placed due South or the South pole of the magnet due North of the magnetic needle, with the other pole vertically above the centre of the needle, the magnetic intensity F at the centre of the needle is along the same direction as the Earth's field. So, the total intensity at the point is $(F + H)$. Let n_0 be the frequency of oscillation in the Earth's field alone and n_1 , the frequency of oscillation in the combined field, when the distance is d . Then,

$$H \propto n_0^2 \quad \text{and} \quad (F + H) \propto n_1^2.$$

$$\therefore \frac{F + H}{H} = \frac{n_1^2}{n_0^2}$$

$$\therefore \frac{F}{H} = \frac{n_1^2 - n_0^2}{n_0^2}$$

Now, $F = \frac{m}{d^2}$ (derived from the Inverse Square Law),

where m is the pole strength and d , distance of the point from the pole.

$$\therefore \frac{\frac{m}{d^2}}{H} = \frac{n_1^2 - n_0^2}{n_0^2}$$

$$\therefore \frac{m}{H} = d^2 \left(\frac{n_1^2 - n_0^2}{n_0^2} \right).$$

Since $\frac{m}{H}$ is a constant, $d^2 \left(\frac{n_1^2 - n_0^2}{n_0^2} \right)$ will be constant. If this is verified, the Inverse Square Law is verified.

d , n_0 , n_1 being known, $\frac{m}{H}$ can be calculated. If the value of H is assumed, m can be calculated.

Tabulate the results as follows :—

I. Earth's field alone.

Trial No.	Time for 25 oscillations	Period T_0	Frequency $n_0 = \frac{1}{T_0}$	n_0^2
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$$\therefore \text{Mean } n_0^2 =$$

II. North pole of magnet due South of needle.

Distance d	Time for 25 oscillations				Period of oscillation T_1	Frequency $n_1 = \frac{1}{T_1}$	n_1^2	$d^2 \frac{(n_1^2 - n_0^2)}{n_0^2}$
	1	2	3	Mean				

$$\therefore \text{Mean value of } d^2 \left(\frac{n_1^2 - n_0^2}{n_0^2} \right) =$$

III. South pole of magnet due North of needle.

Distance d	Time for 25 oscillations				Period of oscillation T_1	Frequency $n_1 = \frac{1}{T_1}$	n_1^2	$d^2 \frac{(n_1^2 - n_0^2)}{n_0^2}$
	1	2	3	Mean				

$$\therefore \text{Mean value of } d^2 \left(\frac{n_1^2 - n_0^2}{n_0^2} \right) =$$

$$\text{IV.} \quad d^2 \left(\frac{n_1^2 - n_0^2}{n_0^2} \right) = \frac{m}{H}.$$

$$\therefore m = H \times d^2 \left(\frac{n_1^2 - n_0^2}{n_0^2} \right).$$

Multiply the mean value of $d^2 \left(\frac{n_1^2 - n_0^2}{n_0^2} \right)$ by the known value of H and calculate m .

EXPERIMENT 74

MIRROR MAGNETOMETER

VERIFICATION OF INVERSE SQUARE LAW

Aim :—To verify the Inverse Square Law using the mirror magnetometer.

Apparatus required :—Mirror magnetometer, short magnet (about 4 cms. long), stand for the same, telescope and scale.

Description of Mirror Magnetometer :—Two or three small bits of steel about 5 mms. long (cut from the main-spring of a watch) are magnetised and cemented to the back of a circular (galvanometer) mirror about 1 cm. in diameter. All the north poles must face the same direction and all the south poles, the opposite direction. The mirror is fixed to a light aluminium or brass frame and suspended vertically by a strand of unspun silk fibre, free from torsion, inside a brass case. The brass case has a glass window in front of the mirror and a circular base provided with levelling screws. The silk fibre is hung from a head which can be rotated. There is sufficient space round the mirror to turn freely and its plane is adjusted to be vertical.

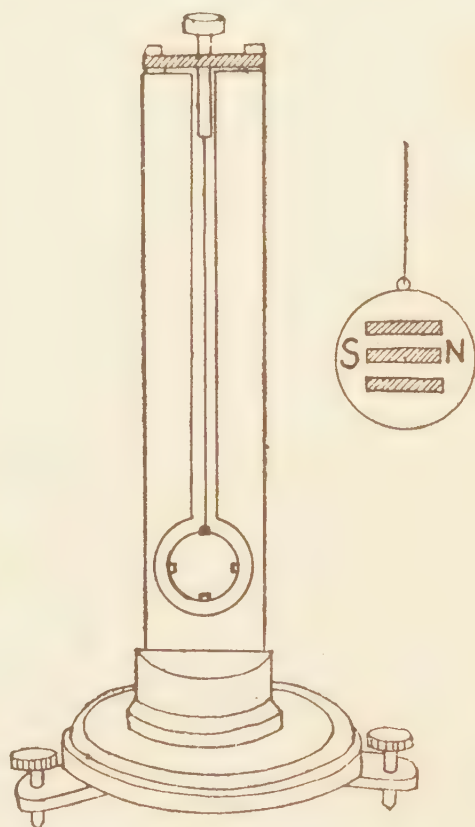


Fig. 151

Procedure :—All magnets are removed to a distance. Two long lines are drawn on the table along and perpendicular to the magnetic meridian respectively. The magnetometer is set up at the point of intersection of the two lines with the plane of the mirror coinciding with the magnetic meridian. The north poles of the magnets at the back of the mirror must be facing north. Then only the mirror will hang freely. Level the magnetometer, so that the plane of the mirror is vertical and it does not stick when it rotates.

Mount the telescope and scale in front of the magnetometer. Fix the scale in the horizontal position. Rotate the telescope, so that its axis is horizontal. Raise or lower it till its axis passes through the centre of the mirror. Adjust the eye-piece so that the cross-wires are distinctly seen. Focus the telescope on the image of the scale seen by reflection at the mirror. Adjust the position of the scale, so that the point of intersection of the cross-wires coincides with a division at the centre of the scale. Note the reading. This is the zero reading.

Place the short magnet horizontally on a wooden stand. Adjust its height, so that it is the same as that of the mirror. Place it on the line drawn perpendicular to the magnetic meridian at a distance of about 100 cms. from the mirror, due east or west of it. Adjust it, so that the axis of the magnet passes through the centre of the mirror.

The mirror is now in the Tan A or End-on-position. Note the reading on the scale, when it becomes steady.

Move the magnet slowly towards the mirror through 10 cms. Note the steady reading. Move it through another 10 cms and note the steady reading. Take readings for three or four distances. Take care to see that the maximum reading does not go beyond the scale.

After taking the reading when the magnet is nearest to the magnetometer, reverse it end for end. Place it at the same distance and note the steady reading. Move it away from the magnetometer by 10 cms. at a time and note the steady readings corresponding to each distance.

[Note:—At each distance, the magnet may be reversed end for end and the readings noted. But this will set up oscillations of the mirror and it may take a long time for the oscillations to die out. So, the above procedure is suggested.]

Transfer the stand with the magnet to the other side of the magnetometer. Repeat the experiment and note the readings corresponding to each distance.

Place the stand on the line representing the magnetic meridian, due north or south of the magnetometer, at a distance

of about 100 cms. from the mirror. Adjust the magnet, so that its axis is perpendicular to the magnetic meridian and the centre of the mirror lies on its perpendicular bisector.

The mirror is now in the Tan B or Broadside-on position. Note the reading on the scale, when the deflection has become steady. Move the magnet by 10 cms. at a time towards the mirror and note the steady readings on the scale. Take readings for the same distances as in the Tan A position.

After taking the reading in the position nearest the mirror, reverse the magnet end for end. Replace it at the same position and note the reading, when the deflection is steady. Move the magnet away, by 10 cms. at a time and note the steady readings corresponding to each distance.

Transfer the magnet to the opposite side of the magnetometer. Taking the same precautions, repeat the experiment and take the readings corresponding to the same distances.

The magnetic intensity F_1 , at any point along the axis of a magnet is given by the formula (derived by assuming the Inverse Square Law),

$$F_1 = \frac{2Md}{(d^2 - l^2)^2} = \frac{2Md}{d^4 \left(1 - \frac{l^2}{d^2}\right)^2} = \frac{2M}{d^3}$$

when l is so small compared with d that higher powers of $\frac{l}{d}$ can be ignored.

Similarly, assuming the Inverse Square Law, the magnetic intensity at any point on the perpendicular bisector of a magnet, is given by

$$F_2 = \frac{M}{(d^2 + l^2)^{3/2}} = \frac{M}{d^3 \left(1 + \frac{l^2}{d^2}\right)^{3/2}} = \frac{M}{d^3}$$

when $\frac{l}{d}$ is so small, that higher powers of $\frac{l}{d}$ can be ignored.

For the same short magnet of magnetic moment M , if d is the same,

$$\frac{F_1}{F_2} = \frac{\frac{2M}{d^3}}{\frac{M}{d^3}} = 2 \quad (i)$$

Hence, the intensity at any point along the axis of a short magnet is *twice* the intensity at a point at the same distance from the centre of the magnet on the perpendicular bisector, provided that the distance is large compared with the length of the magnet.

In the above experiment, if θ_1 is the mean deflection in the Tan A position, for a certain distance,

$$F_1 = H \tan \theta_1$$

If θ_2 is the mean deflection in the Tan B position, for the same distance,

$$F_2 = H \tan \theta_2$$

$$\therefore \frac{F_1}{F_2} = \frac{H \tan \theta_1}{H \tan \theta_2} = \frac{\tan \theta_1}{\tan \theta_2} \quad (ii)$$

combining (i) and (ii)

$$\frac{\tan \theta_1}{\tan \theta_2} = 2.$$

This was derived by Gauss and experimentally verified. Hence, it is known as Gauss' method of verifying the Inverse Square Law.

Again, let the distance between the centre of the mirror and the scale be D , and the displacement on the scale s , corresponding to a deflection θ of the mirror. Since the reflected ray turns through twice the angle through which the mirror turns,

$$\tan \theta = \frac{s}{2D}$$

Hence, if s_1 is the mean displacement on the scale corresponding to a deflection of θ_1 in the Tan A position, and s_2 , the mean displacement corresponding to a deflection of θ_2 in the Tan B position, for the same distance d ,

$$\frac{\tan \theta_1}{\tan \theta_2} = \frac{\frac{s_1}{2D}}{\frac{s_2}{2D}} = \frac{s_1}{s_2}$$

$$\therefore \frac{s_1}{s_2} = 2.$$

Tabulate the results as follows :—

Distance between scale and centre of mirror = D cms.

Zero reading on scale =

Distance between centre of magnet and centre of mirror	Displacement in Tan A position					Displacement in Tan B position					Mean S_2	$\frac{\tan \theta_1}{\tan \theta_2} = \frac{S_1}{S_2}$
	Magnet East of Mirror		Magnet West of Mirror		Mean S_1	Magnet North of Mirror		Magnet South of Mirror				
	N pole facing West	N pole facing East	N pole facing West	N pole facing East		N pole facing West	N pole facing East	N pole facing West	N pole facing East			
	s'	s''	s'''	s''''		s'	s''	s'''	s''''			

$\therefore$ Mean value of $\frac{S_1}{S_2} =$

Note :—The ratio of $\frac{l}{d}$ must be less than $\frac{1}{30}$ for satisfactory results. You must use a powerful magnet.

Determination of M and H

Find the mass W of the magnet used, accurately. Measure its length a and breadth b. If the magnet is rectangular, its moment of Inertia I about an axis passing through its centre is given by,

$$I = W \left(\frac{a^2 + b^2}{12} \right).$$

Remove the torsion, if any, in the suspension fibre in the vibration box, place the magnet in the stirrup and find its period of oscillation T. (Vide experiment 71).

$$T = 2\pi \sqrt{\frac{I}{MH}}.$$

$$\therefore MH = \frac{4\pi^2 I}{T^2}$$

Calculate the mean value of $\frac{M}{H}$ from the readings taken in the experiment earlier, in the Tan A and Tan B positions,

In the tan A position, $\frac{M}{H} = \frac{(d^2 - l^2)^2}{2d} \times \tan \theta$
 $= \frac{(d^2 - l^2)^2}{2d} \times \frac{s_1}{2D}.$

In the tan B position, $\frac{M}{H} = (d^2 + l^2)^{3/2} \times \tan \theta_2$
 $= (d^2 + l^2)^{3/2} \times \frac{s_2}{2D},$

From the known values of M/H and $\frac{M}{H}$, calculate M and H
 (Vide experiment 71).

SECTION VII

ELECTRICITY

ELECTRICAL ACCESSORIES

A number of electrical accessories are in common use in most electrical experiments. They are assembled together and connected so as to form circuits, for the electric current to pass through them without break. The common accessories are connecting wires, terminals, batteries, galvanometers, ammeters, voltmeters, resistances, keys, etc. A good knowledge of their use is essential for successful performance of experiments.

Connecting wires and terminals

The various instruments and accessories in a circuit are connected with each other by connecting wires. These wires are of copper, insulated by double covered cotton. Silk or rubber or plastic insulated wires also may be used. The copper wire is generally of gauge 20 or 22 S.W.G. The resistance of the connecting wires is so small that it can be ignored. The ends of these wires must be bared and cleaned with sand paper before they are used for connections. All the electrical instruments and accessories have terminals fixed on them. The end of the connecting wire must be inserted into or round the terminal in the clockwise direction and secured firmly. If the contact is loose, either no current will pass or a large resistance will be introduced into the circuit. After connecting a wire to a terminal, gently pull it to see if it is firm.

Batteries

In every circuit, a source of electric current must be included for the supply of current. Batteries are used for the purpose. The primary batteries used are the **Lechlanche's cell** and the **Daniel's cell**. Secondary batteries used are **accumulators** (or **storage batteries**).

Lechlanche's cell :—It is an easily prepared single fluid cell, the liquid being a concentrated solution of ammonium chloride.

The positive plate is a carbon rod surrounded by manganese-di-oxide kept in a porous pot. The negative pole is an amalgamated zinc rod. It has an E.M.F. of about 1.45 volts. But its depolarising action is slow and it has a large internal resistance. So, only when small, momentary currents are needed, it is used.



Fig. 152

Daniel's cell:—The positive plate is a plate of copper immersed in saturated copper sulphate solution. The negative pole is an amalgamated zinc rod immersed in dilute sulphuric acid kept in a porous pot. A freshly

prepared Daniel's cell gives a constant E.M.F. of 1.08 volts, if it is not used for drawing currents. Its depolarising action is better than the Leclanche's and its internal resistance also is less. When a standard cell is not available, the Daniel's cell can be used instead, if very high precision is not required.

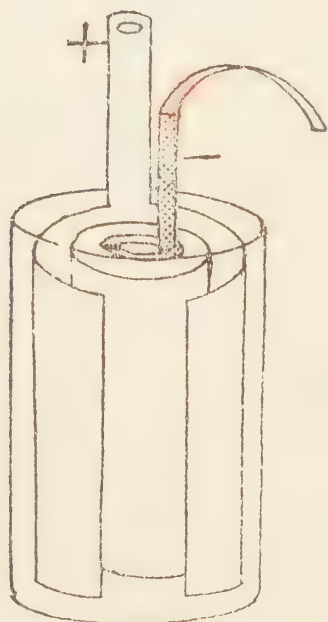


Fig. 153

Accumulator or storage battery is a secondary cell, which has to be periodically charged after being discharged. There are two types—the *acid* and the *alkaline*. In the *acid type*, dilute sulphuric acid of a specified density is used with lead (negative pole) and lead per-oxide (positive pole) plates dipped in them. The density of the acid and the voltage indicate the charged condition of the cell. A freshly charged accumulator gives a steady, constant E.M.F. of

2 volts and can be used for drawing large currents. Its internal resistance is negligible. For most experiments, the source of electricity used is this type of accumulator. *But it is absolutely essential that, whenever an accumulator is used, there must be no short circuiting of the poles of the cell.* Since its internal resistance is negligible, any short circuiting of the poles will ruin the cell.

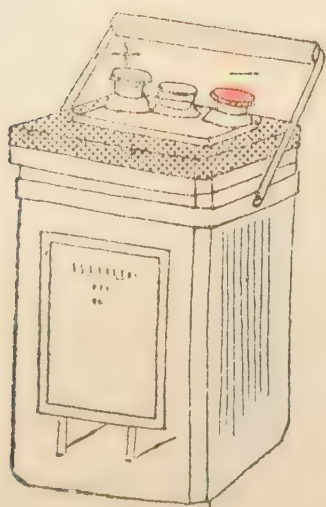
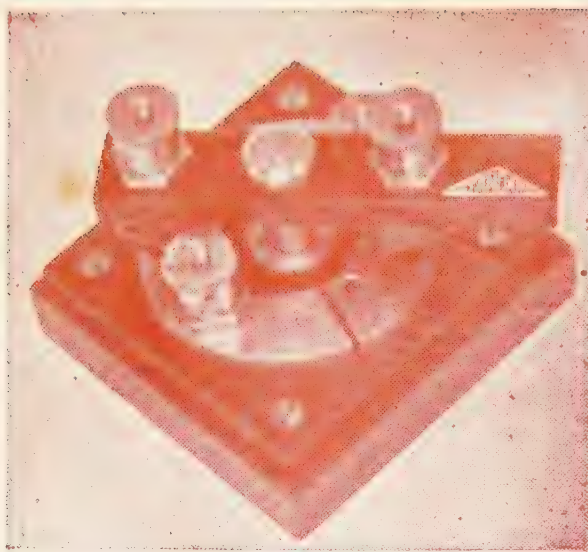


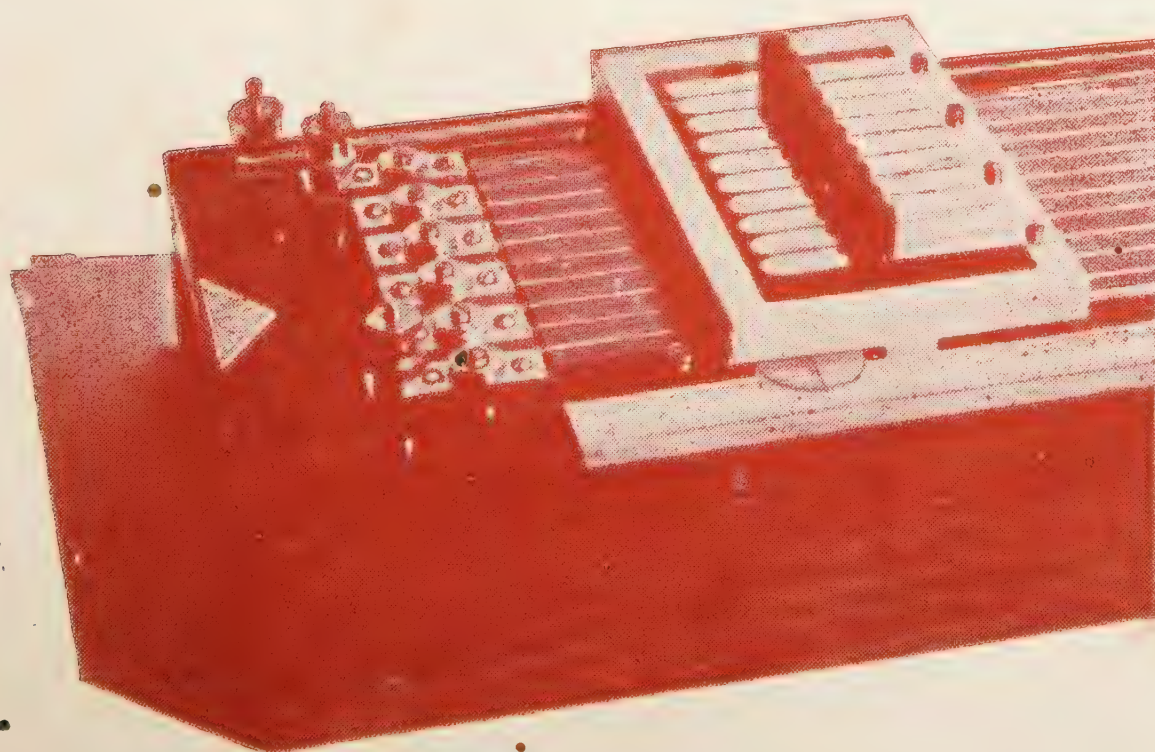
Fig. 154



1. Commutator



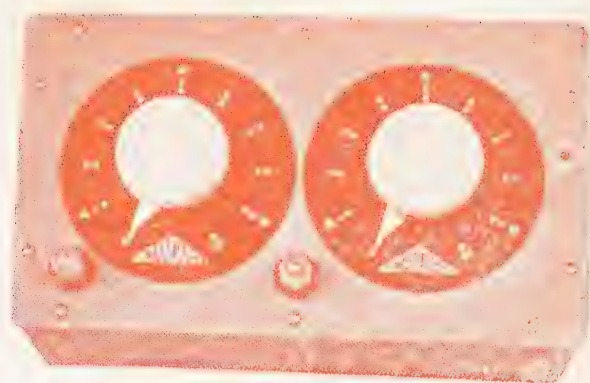
2. Rheostats



3. Potentiometer



4. Four Dial Resistance Box



5. Two Dial Resistance Box



6. Three Dial Resistance Box

The alkaline type—known as the Ni-Fe cell—has two plates of Ni and Fe dipped in strong KOH solution. These cells are more robust. They give an E.M.F. of about 1.3 volts. But the E.M.F. is not so steady as the acid type. Large currents can be drawn from them and they do not need so much attention as the acid type.

Mains :—In certain experiments, the required current can be drawn from the mains, taking the necessary precautions.

Galvanometers

Galvanometers are used in circuits, mostly for indicating or detecting currents, with the exception of the tangent galvanometer, which is used for measuring current in absolute measure.

Tangent galvanometer :—It consists of a circular coil of insulated wire, wound over a vertically mounted wooden or brass ring, with a deflection magnetometer placed at its centre. When a current is passed through the coil, the magnetic intensity at the centre of the coil is perpendicular to the plane of the coil. So, if the coil is set up in the magnetic meridian, the intensity F at the centre of the coil will be perpendicular to the magnetic meridian. Hence, the magnetic needle at the centre will be deflected through an angle θ , such that $F = H \tan \theta$, where H is the horizontal component of the earth's field. $F = \frac{2\pi nC}{10r}$ where n is the number of turns of wire in the coil, r , the mean radius of the coil and C , the current in amperes passing through the coil. Hence,

$$\frac{2\pi nC}{10r} = H \tan \theta$$

$$\therefore C = \frac{10r H \tan \theta}{2\pi n}$$

Thus, C can be calculated from the known values of r , H , n and θ . Refer to experiment 75 for fuller details about the tangent galvanometer and for the precautions to be taken in its use.

As the tangent galvanometer is not sensitive enough for the accurate measurement or detection of current, it is rarely used for such purposes.

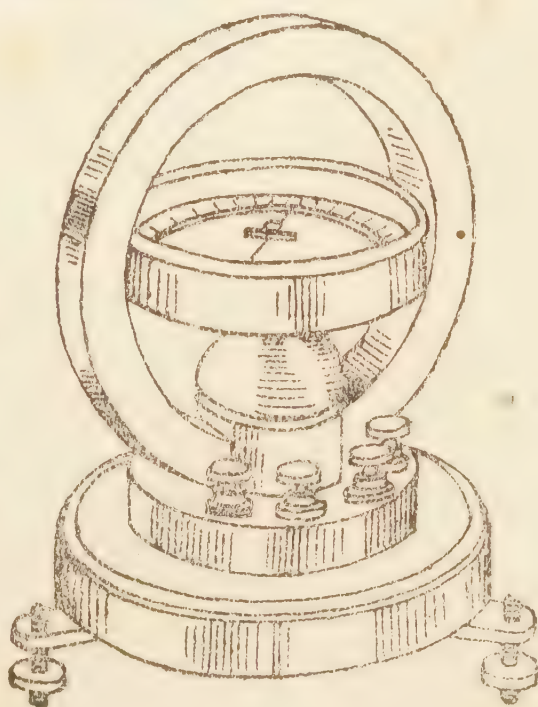


Fig. 155

Moving coil galvanometer :—For most experiments, a moving coil galvanometer is used for the detection of current. It consists of a coil of wire, suspended freely between the poles of a powerful permanent magnet of the horse-shoe type.

In the **table type** of galvanometer, a pointer moving over a graduated scale is attached to the coil. Current passes into the

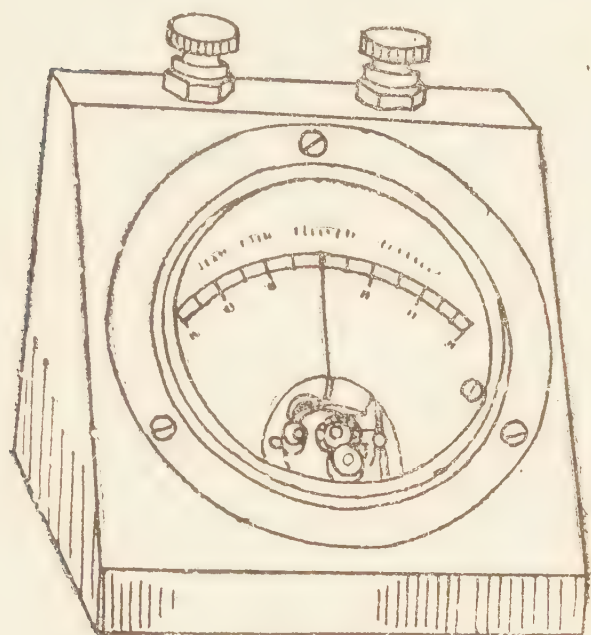


Fig. 156

coil and out, through phosphor bronze spirals of wire, which do not impede the movement of the coil. In the undeflected position, the plane of the coil is parallel to the lines of force. When a current passes through it, it is deflected, the deflection being proportional to the current passing.

In the **unipivot type**, the coil is balanced on one pivot only. Hence, its movement is less restricted. The galvanometer is more sensitive.

In the **moving coil mirror galvanometer**, the coil is suspended by a phosphor bronze strip. A small mirror is fixed to the coil. A spot of light is directed on to the mirror. After reflection, it is caught on a translucent scale. When the coil is deflected, the mirror also is deflected. So, the spot of light moves on the scale. From the deflection of the spot of light, the current can be estimated.

These galvanometers are very sensitive. They are mostly used for detection and measurement of minute currents and particularly in circuits for obtaining balance. Moving coil instruments are not affected by magnetic fields. *As they are very sensitive, only small currents must be passed through them.*

Ammeters

Ammeters are instruments used for direct measurement of current in amperes. Ammeters in general use are moving coil

galvanometers, with *low resistance shunts* connected in *parallel* with them. When a current is passed through the combination, the major part of it passes through the shunt, while only a fraction passes through the galvanometer. Let G be the resistance of the galvanometer, S , that of the shunt, C , the current passing through the combination, C_g , the current passing through the galvanometer and C_s , the current passing through the shunt. Then,

$$C = C_g + C_s.$$

$$\text{and } C_g \cdot G = C_s \cdot S.$$

$$\therefore \frac{S}{S + G} = \frac{C_g}{C_g + C_s} = \frac{C_g}{C}$$

$$\therefore C = C_g \times \frac{S + G}{S}$$

By suitably adjusting the value of S , any fraction of the total current can be passed through the galvanometer. Thus, let one division on

the galvanometer indicate one milliampere. By making $\frac{G + S}{S}$ equal to 1000, one ampere passed through the combination will produce a deflection of one division only in the galvanometer which will now represent one ampere. Thus, by choosing S properly, different ranges can be obtained.

The resistance of an ammeter is almost the same as that of the shunt. Hence, it will be small. If the readings of an ammeter are to be relied upon, it has to be calibrated periodically.

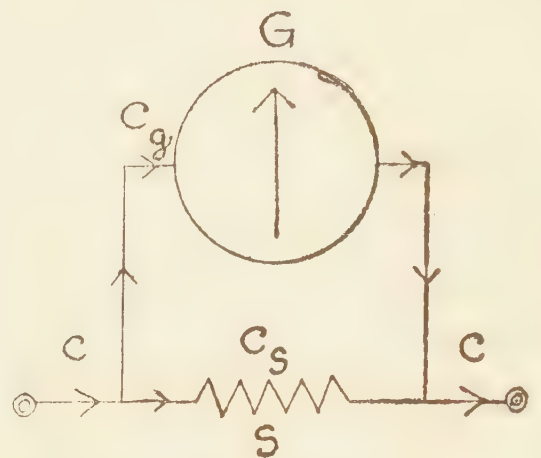


Fig. 157

Voltmeters

Voltmeters are used for the measurement of potential differences in volts. A voltmeter in general use is a moving coil galvanometer with a *large resistance connected in series* with it. When a P.D. is applied to the combination, only a small current passes through it, as the total resistance is large. Let G be the resistance of the galvanometer and R , that of the series resistance.

If a P.D. of V volts is applied to them, the current C produced will be given by,

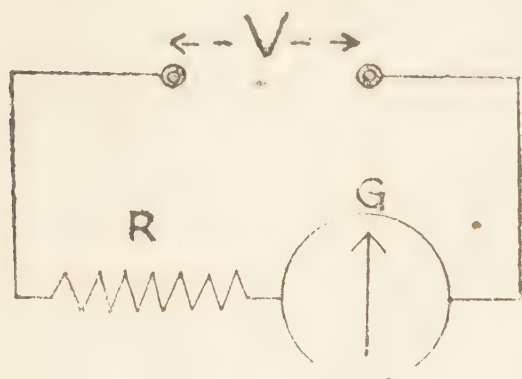


Fig. 158

$$C = \frac{V}{G + R} \text{ or } V = CG + CR$$

If CG is equal to v , then

$$\frac{V}{v} = \frac{CG + CR}{CG} = \frac{G + R}{G}$$

By suitably choosing R , $\frac{V}{v}$ can be

adjusted to be any ratio. Thus, let one division of the galvanometer indicate one millivolt. By connecting in series with it a resistance R equal to $999 G$ ohms and applying a P.D. of one volt to the combination, a deflection of one division only will be produced in the galvanometer. But it will now indicate one volt. By choosing R suitably, different ranges can be obtained.

The resistance of a voltmeter is generally large due to the large resistance connected in series with the galvanometer. Voltmeters have to be calibrated periodically.

Resistances

Resistances are used in electrical circuits for regulating or altering the currents in them. They are constructed of greater or less lengths of wire of *german silver*, or *platinoid* or *nichrome* or *manganin* or *constantan* or *minalpha* depending on the particular instrument. For standard resistances, materials of low temperature coefficient like *manganin* or *constantan* or *minalpha* are chosen.

Rheostats are adjustable resistances. They are used for continuously varying the resistance in circuits, when it is unneces-

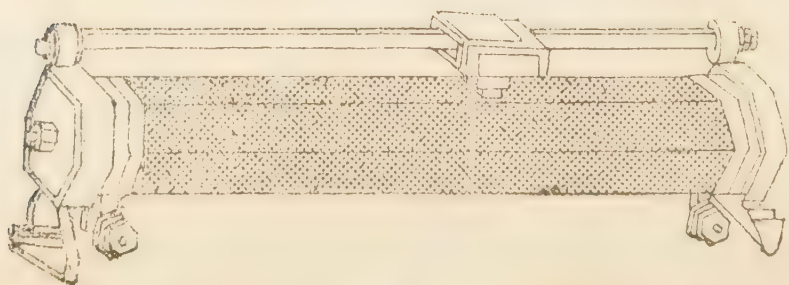


Fig. 159

sary to know the value of the resistance included in the circuit. The resistance wire is closely wound over a long bobbin of porcelain or other insulating material. The two ends

are connected to two terminals. A sliding contact moving on a metallic rod enables you to include any desired part of the resistance in the circuit. A terminal is fitted to the metallic rod. When one of the end terminals and the terminal connected to the sliding contact are used, it functions as an adjustable resistance.

For every rheostat, there is a current rating, i.e. the maximum safe current. It must never be exceeded.

Resistance boxes:—A resistance box consists of a series of coils of known, specified resistances. They are generally insulated wires of manganin or constantan having a low-temperature coefficient, wound on wooden bobbins, *non-inductively*. For larger resistances, finer wires are used. The bobbins are fixed to the under surface of the top of the box.

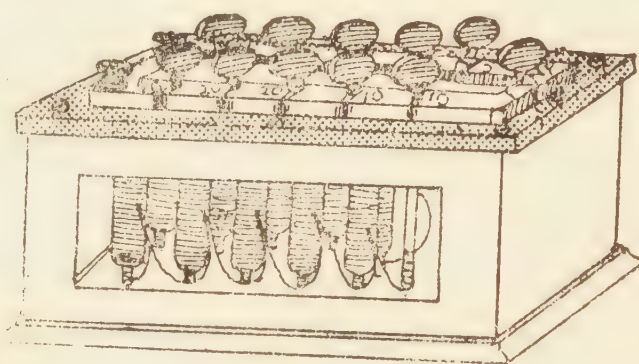


Fig. 160

The top is generally of ebonite. On the upper side, a series of stout brass blocks are fixed close to but separated from each other. The sides of these blocks facing each other have grooves in them which form conical sockets. Brass plugs are provided which fit tightly into these sockets. Short thin brass rods fixed to the blocks project inside the box. The ends of each of the coils are soldered to these rods, so that each block is connected to the next one through a resistance coil. When the plug is inserted in the socket above, the two neighbouring blocks get short-circuited and the resistance underneath is cut out. If the plug is removed, the resistance gets included in the circuit.

The resistances of the coils are arranged in a regular series, 1, 2, 2, 5, 10, 20, 20, 50, etc. Hence, by removing the particular plugs, any desired resistance can be introduced into the circuit.

If there is loose contact between a plug and the socket, that resistance will get introduced into the circuit, without the knowledge of the experimenter. So, the plugs must be inserted into the sockets with a clockwise screw motion every time, to ensure good contact.

In most boxes, there will be an “infinity” plug. Under this socket, there will be *no* resistance coil. When the plug is removed, the circuit will be broken.

Dial pattern boxes also are often used. They have in them a group of ten 1 ohm coils connected in series, a group of ten 10 ohm coils connected in series, and so on. The ends of consecutive coils are soldered to the bottom of brass studs arranged in a circle on the top of the boxes. A sliding metallic brush operated by a knob at the centre makes contact with any stud. By operating these knobs, any desired resistance can be obtained. The nuisance due to loose contacts prevalent in plug type boxes is avoided in this type of boxes.

Resistance coils :— Individual resistance coils are required for various purposes. Resistance coils of the desired value are wound on bobbins non-inductively. Their ends are soldered to thick brass strips attached to terminals.

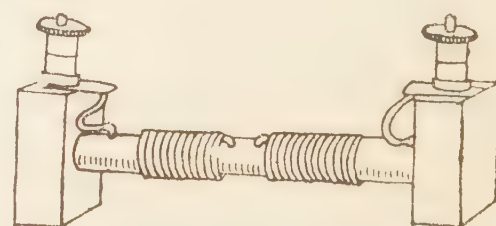


Fig. 161

As resistances get heated when currents are passed, it is of the utmost importance that large currents are *not* passed through standard resistance coils.

A safety high resistance is generally used in series with sensitive galvanometers to prevent damage to them. It is of the order of 10,000 to 20,000 ohms. It has fixed on it a plug key, to the terminals of which, the ends of the resistance are connected. When the plug is inserted, the resistance gets cut out. When the plug is removed, the resistance is introduced in the circuit.

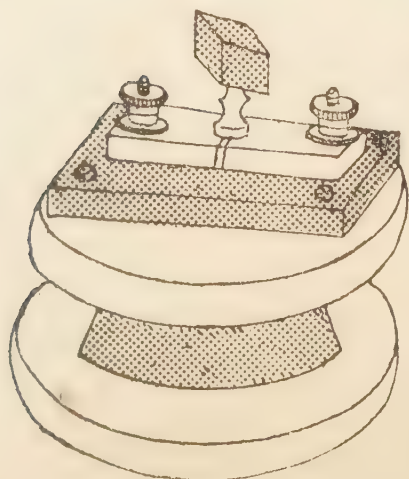


Fig. 162

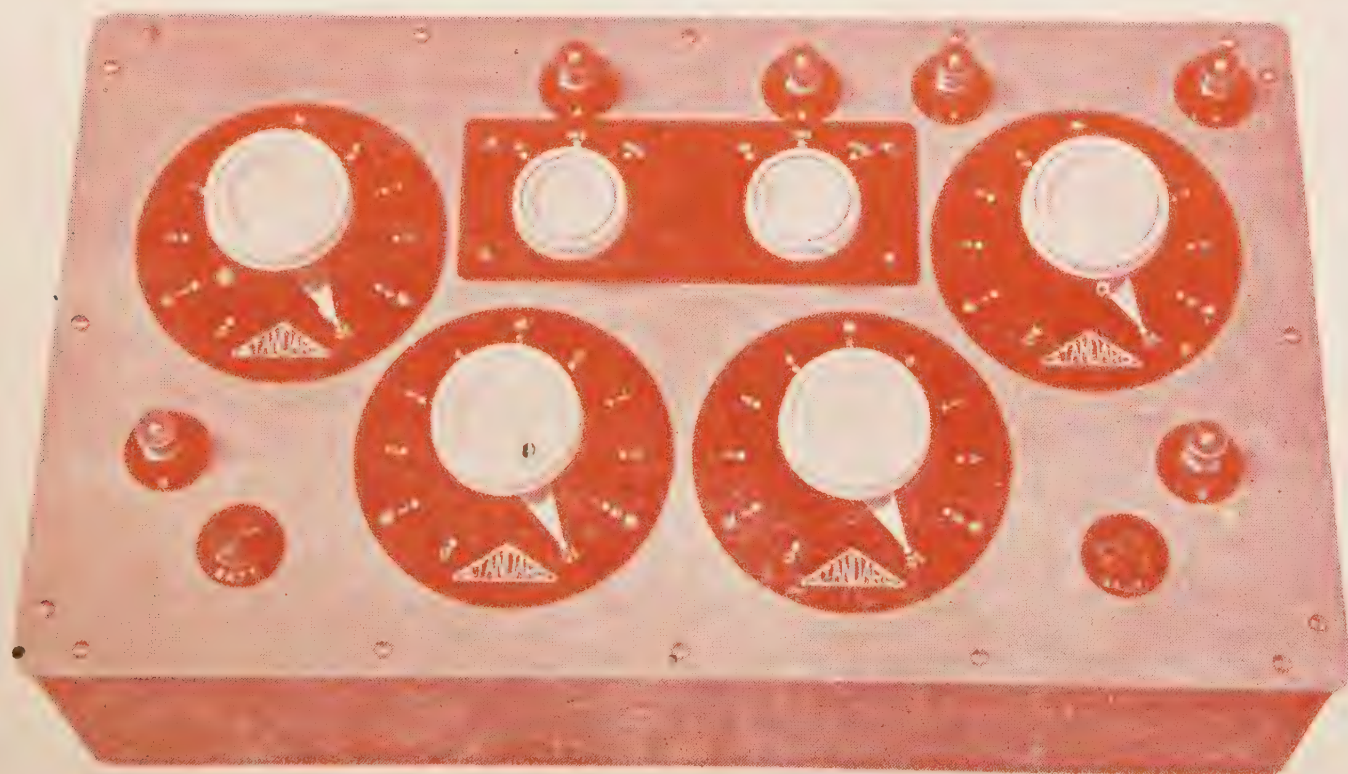
Keys

Keys are used not only for closing or opening circuits but modified forms are used for reversing currents, charging and discharging condensers, etc.



7. Standard Resistance with Potential and Current terminals

Standard Resistance



8. Dial Pattern Post office Box



9. Joule's Galorimeter



10. Double Successive Key



11. Standard Solenoid

A **Tap key** is a simple key used for momentarily closing circuits. A metallic strip is fixed to one terminal in the key and a metallic stud, to another terminal in it. The strip stands normally a little above the stud. When it is pressed, it comes in contact with the stud and metallic connection is established. The key can be included in a circuit and used for momentarily closing the circuit.

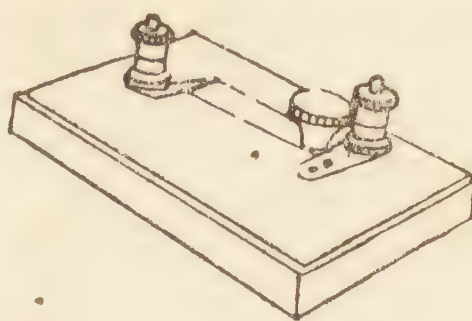


Fig. 163

A **Plug key** consists of two rectangular brass blocks, fitted close to but not touching each other on a base board of teakwood or ebonite. The sides of the blocks facing each other, have grooves in the middle, so as to form a conical socket. A brass plug fits into the socket. Terminals are fixed at the ends of the blocks. The plug key is included in a circuit, for closing or opening it. When the plug is in the socket, the circuit is closed. When it is removed, it is open.

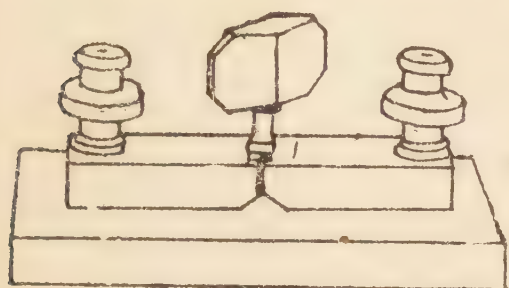


Fig. 164

Commutator or current reverser

In many circuits, it may become necessary to reverse the current either in the whole of the circuit or part of it. This is effected by using a commutator or current reverser. It has in it four terminals 1, 2, 3, 4. By a lever arrangement, it is possible to

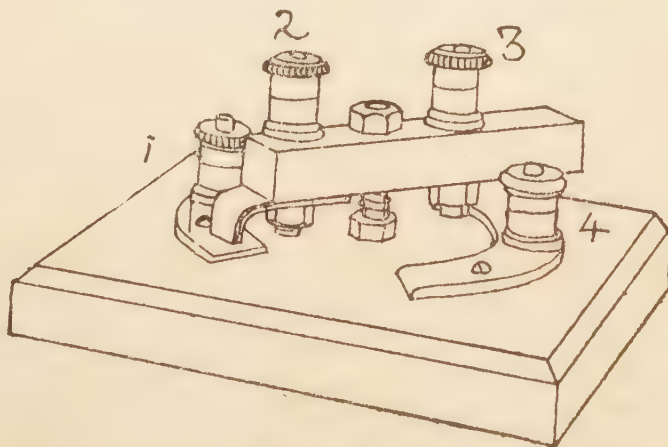


Fig. 165

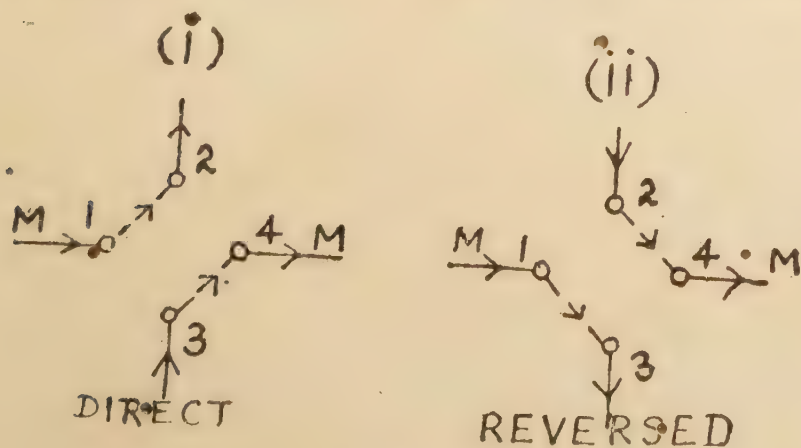


Fig. 166

establish contact between 1, 2 and 3, 4, or between 1, 3 and 2, 4. 1 and 4 are connected to the main circuit, while 2 and 3 to the part of the circuit in which the current has to be reversed.

The Pohls commutator has in it four cups with mercury.

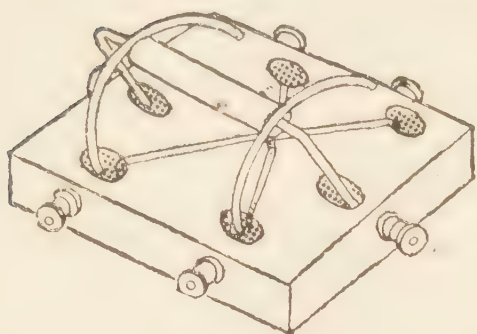


Fig. 167

Cross metallic strips link the opposite cups. A terminal is fitted to each cup. There are two other mercury cups with independent terminals fitted to them. A rocker is used for reversing the current. Let A, B be the independent terminals. They are connected to the main circuit. C, D

are the terminals on one side and E, F on the other. One of these pairs is connected to the secondary circuit.

Cross-pieces connect C, F and D, E. When the rocker is on one side there is metallic connection between A, C and B, D. When the rocker is swung over, connection is established

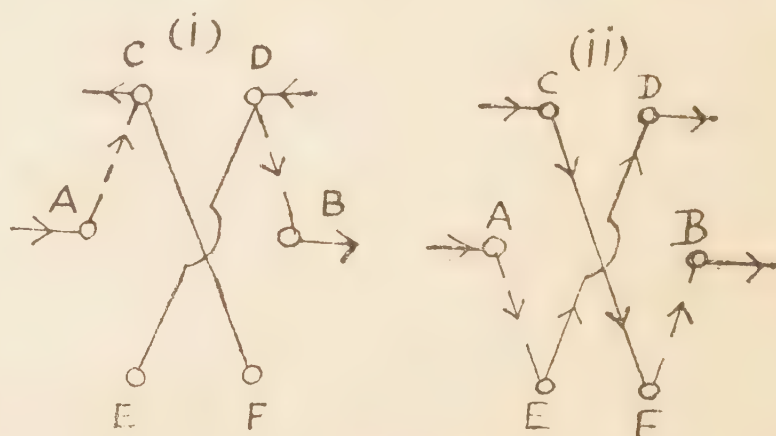


Fig. 168

between A, E i.e. A, D and B, F i.e. B, C. Thus, the current gets reversed in the secondary circuit.

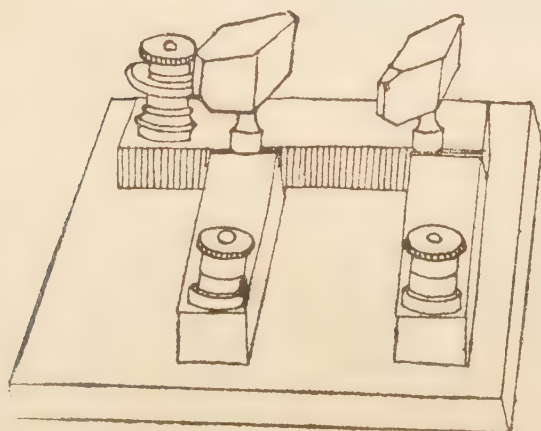


Fig. 169

Two-way key :—This has in it a brass block with a terminal A fixed on it. Two other brass blocks are fitted by its side with terminals B, C, fixed on them. By means of a plug, metallic connection can be established between A and B or A and C. Thus, either the circuit connected to A, B or A, C can be closed.

Double-pole double-throw key :—is used for including in a circuit, one or the other of two resistances or cells, etc. It has in it six terminals A, B, C, D, E, F. A, B are connected to the main circuit. C, D and E, F are respectively connected to the two resistances or cells. By a lever arrangement, contact can be

established between A C, B D or between A E, B F. Thus, one or the other can be included in the main circuit.

If the cross-pieces are removed, a Pohl's commutator (fig. 168) can be used for this purpose.

Charge and discharge key :—Is used for charging and dis-charging a condenser. It has three terminals

fixed to it. Suppose they are x, y, z. x is a common terminal.

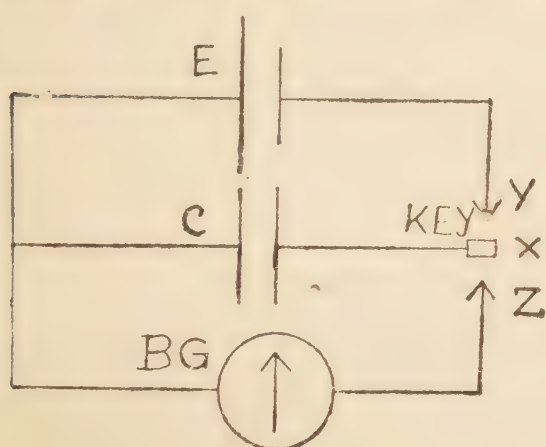


Fig. 171

The condenser C is connected through x and y to a cell E. When x and y are connected, the condenser gets charged. The condenser is connected through x and z to a ballistic galvanometer BG. When x and z are connected, the condenser gets discharged through the galvanometer.

A morse key (fig. 172) can also be used for the above purpose.

General instructions for electrical experiments

(1) Draw a neat and clear circuit diagram before you start the experiment.

(2) All the contacts must be clean.

(3) After making each connection, test it to see, if it is tight.

(4) A circuit must be closed, only when you are taking a reading. So, to control it, always include a plug key in the circuit. When not required, keep the circuit open.

(5) The connecting wires must be neatly disposed of, so as not to cross each other or come in contact with each other. An elegant method is to have all of them wound in the form of spirals before starting the experiment. You can use a pencil or a glass tube for the purpose.

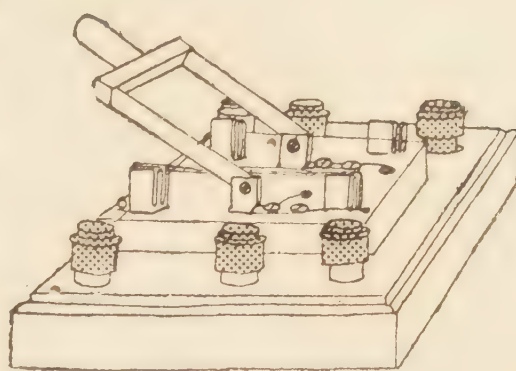


Fig. 170

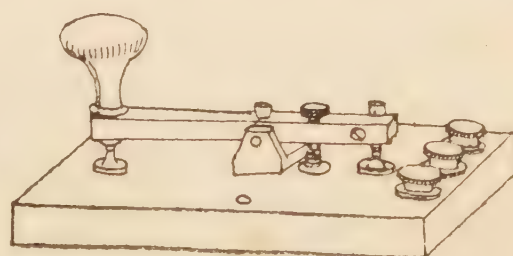


Fig. 172

(6) You must never close a circuit, without seeing whether there is sufficient resistance in it. This is particularly important when you are using an accumulator. It has negligible internal resistance. So, if there is not sufficient resistance in the circuit, it will get short-circuited and very large currents will be drawn from it.

(7) You must always use a safety high resistance along with a sensitive galvanometer. It must be cut out only when a very small current passes through the galvanometer. In the absence of a high resistance, you may use a small length of resistance wire and connect it in parallel to the two terminals of the galvanometer. It will act as a low resistance shunt and prevent damage to the galvanometer.

EXPERIMENT 75

TANGENT GALVANOMETER

Calibration of ammeter

Aim :—To measure the absolute value of a current using a tangent galvanometer and calibrate an ammeter.

Apparatus required :—Two or three accumulators, tangent galvanometer, ammeter, commutator, rheostat.

Description of apparatus :—The tangent galvanometer consists of a coil of insulated wire wound over a circular frame of wood or brass, mounted vertically on a base provided with levelling screws. The number of turns of wire in the coil depends on the current to be measured. The diameter of the coil is about 7.5 to 10 cms. A deflection magnetometer is mounted at the centre of the coil on a vertical support, such that the centre of the magnetic needle coincides with the centre of the coil. The ends of the coil of wire are connected to two terminals fixed on the base of the instrument.

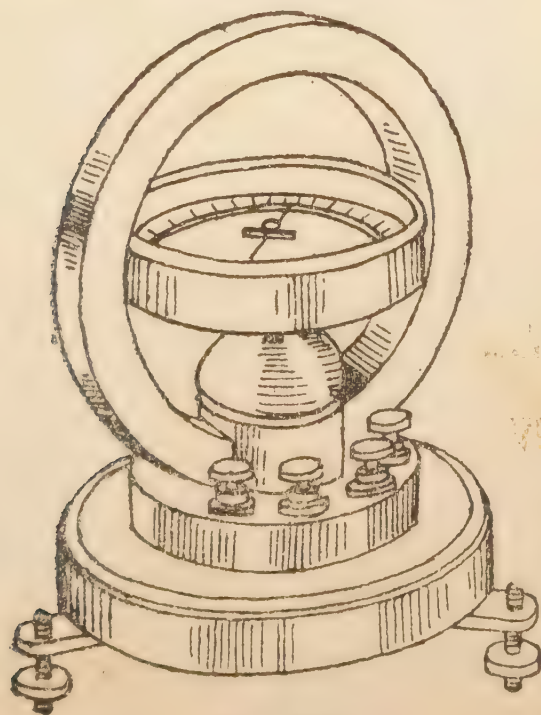


Fig. 173

For this experiment, use a coil of 3 to 5 turns of insulated thick copper wire. If the tangent galvanometers available in the laboratory do not have such a coil, prepare one by winding the necessary turns of wire over the circular frame.

Procedure :—Connect up the battery of two or three accumulators, a plug key, the ammeter (range 0 to 3 amps.), a rheostat (range 10 to 15 ohms., of the required current carrying capacity) in series with the tangent galvanometer coil through a commutator.

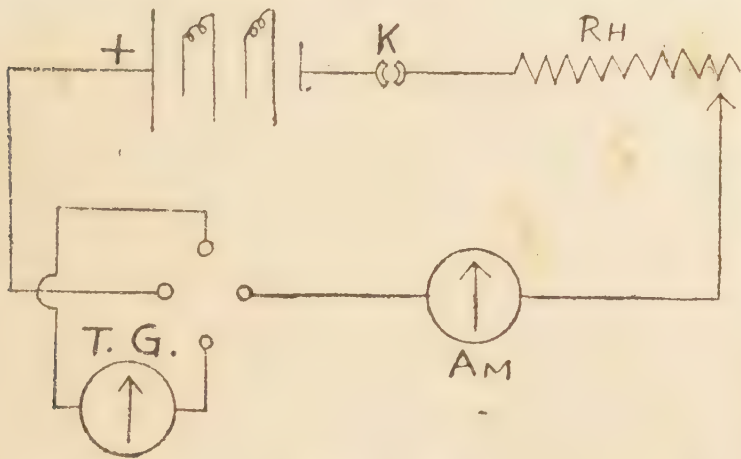


Fig. 174

Have no magnets or magnetic substances near the tangent galvanometer.

The rheostat must be kept at a distance from it, since when a current passes through the rheostat, the magnetic field produced may affect the magnetic needle in the magnetometer. The ammeter also must be at a distance from the magnetic needle.

Level the galvanometer, so that the needle moves freely. Turn the plane of the coil so as to be in the magnetic meridian. Rotate the magnetometer, so that the aluminium pointer reads zero, zero. The commutator is connected to the galvanometer, so that the current passing through it can be reversed, while in the rest of the circuit, it passes in the same direction.

Adjust the slider on the rheostat, so as to include the whole of the resistance in the circuit to start with. Close the circuit by inserting the plug in the key. Note the deflection in the tangent galvanometer. Adjust the rheostat so that the ammeter reads, say, 0.3 of an ampere. [Ascertain up to what value of current and in how many steps, the ammeter has to be calibrated.] Note the deflections at both ends of the pointer in the magnetometer. Reverse the current in the tangent galvanometer coil and note the deflections again. Adjust the rheostat, so that the ammeter reads 0.6 of an ampere. Note the deflections in the galvanometer. Reverse the current and note the deflections. Proceeding in this

manner, find the deflections in the tangent galvanometer, corresponding to the ammeter readings of 0.9, 1.2, 1.5, etc. amperes. The maximum safe current depends on the galvanometer coil. For each reading, reverse the current in the galvanometer and note the deflections.

Increase the resistance in the rheostat and reduce the readings of the ammeter to 1.5, 1.2, 0.9, 0.6, and 0.3 amperes. In each case, note the deflections in the tangent galvanometer, as before.

Note :—It must be remembered that the tangent galvanometer is most sensitive, when the deflection is 45° . Deflections above 60° and below 30° will not give accurate results and must be avoided.

Measure accurately the circumference of the coil used and calculate its radius. Find out the number of turns in the coil.

Theory:—When a current of C amperes passes through a circular coil of wire of n turns of mean radius r , the magnetic intensity F produced at the centre of the coil is given by

$$F = \frac{2\pi nC}{10r}$$

This is perpendicular to the plane of the coil. Since the galvanometer coil is in the magnetic meridian, the above intensity is perpendicular to the magnetic meridian. If the deflection in the magnetometer is θ ,

$$F = H \tan \theta$$

where H is the horizontal component of the earth's field. Combining the two equations,

$$\frac{2\pi nC}{10r} = H \tan \theta$$

$$\therefore C = \frac{10rH}{2\pi n} \tan \theta \text{ amperes.}$$

C can be calculated from the known values of r , n , H and θ .

Correct the corresponding readings in the ammeter using the calculated values.

Tabulate the results as follows :—

Radius of coil = cms.
Number of turns of coil =
Horizontal component of the Earth's field = gauss.

Ammeter reading	Deflection								Mean θ	Tan θ	Current calculated $\frac{10rH}{2\pi n} \tan \theta$	Correction
	Current decreasing				Current increasing							
	Direct		Reversed		Direct		Reversed					
	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8				

EXPERIMENT 76

FIELD ALONG THE AXIS OF A COIL CARRYING
CURRENT—DEFLECTION MAGNETOMETER

Aim :—(A) To measure the magnetic intensity along the axis of a circular coil carrying current using a deflection magnetometer and to calculate the current and (B) to determine the moment of a magnet.

Apparatus required :—Field along axis of coil apparatus, deflection magnetometer, two or three accumulators, ammeter, rheostat, commutator, plug key, magnet.

Description of apparatus :—A coil of thick insulated wire of 5 to 10 turns is wound over a circular frame (ring shaped), 15 to 20 cms. in diameter.

This is fixed vertically on a suitable support. A wooden platform about 80 cms. long and 6 to 8 cms. broad is fitted inside the ring horizontally, with equal lengths projecting on both sides of the coil. It is adequately supported at the two ends

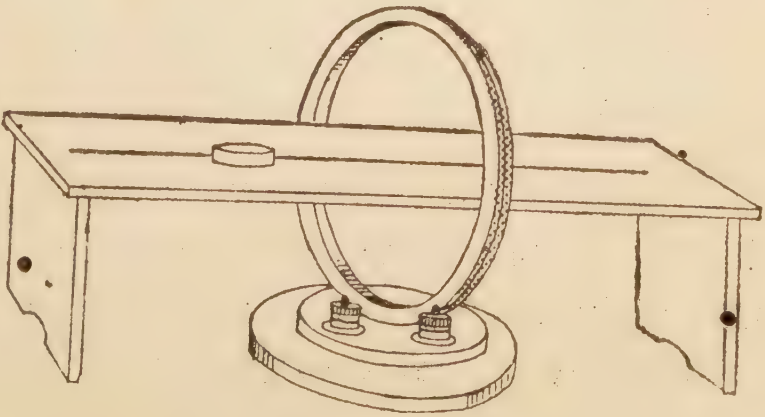


Fig. 175

When a deflection magnetometer is placed on the platform, the centre of the magnetic needle lies in the horizontal plane passing through the centre of the coil.

(A) Measurement of current

Procedure :—Connect up the battery of two or three accumulators, the plug key, the ammeter (of range 0 to 3 amperes), and the rheostat (of range 10 to 20 ohms and of sufficient current carrying capacity) in series with the coil through the commutator (fig. 174).

Turn the coil so as to be in the magnetic meridian, ascertained by using a compass needle. Do not keep the ammeter or the rheostat near the coil. Place the deflection magnetometer on the platform with the centre of the needle, at a distance of, say, 5 cms. from the centre of the coil, along its axis. Rotate it, so that the aluminium pointer reads zero, zero.

To start with, include the maximum resistance in the rheostat and close the circuit. Adjust the rheostat, so that the ammeter indicates a current of 1 ampere. Note the deflections at both ends of the pointer in the deflection magnetometer. This deflection must not exceed 60° . Reverse the current in the coil and again note the deflections.

Open the circuit. Move the magnetometer along the axis, away from the centre of the coil by 5 cms. Close the circuit and note the deflections. Reverse the current and again note the deflections. Move the magnetometer along the axis of the coil, so that its centre is at 15 cms, 20 cms, 25 cms. etc., from the centre of the coil. In each position, pass the current through the coil in both directions and note the corresponding deflections in the magnetometer.

Transfer the magnetometer to the other side of the coil. Place it at the same distances from the centre of the coil. In each position, pass the current through the coil in both directions and note the corresponding deflections in the magnetometer.

Repeat the experiment using currents of 1.5, 2.0, etc., amperes. See that the deflections range from 30° to 60° .

Note the number of turns in the coil. Measure accurately the circumference of the coil and calculate its radius.

FIELD ALONG THE AXIS OF A COIL CARRYING CURRENT— 329
DEFLECTION MAGNETOMETER

Theory :—The magnetic intensity F at any point on the axis of a coil of n turns of radius r cms., when a current of C amperes passes through it, is given by,

$$F = \frac{2\pi nr^2 C}{10 (r^2 + d^2)^{3/2}}$$

where d is the distance of the point from the centre of the coil along its axis.

If the coil is placed along the magnetic meridian, this intensity will be perpendicular to the magnetic meridian. A magnetometer placed at the point will indicate a deflection given by,

$$F = H \tan \theta$$

Combining the two equations,

$$\frac{2 \pi n r^2 C}{10 (r^2 + d^2)^{3/2}} = H \tan \theta$$
$$\therefore C = \frac{10 (r^2 + d^2)^{3/2} \times H}{2\pi n r^2} \tan \theta$$

From the known values of n, r, d, H and θ, C can be calculated.

Tabulate the results as follows :—

- Number of turns of coil =
- Radius of coil = cms.
- Horizontal component of the earth's field = gauss.
- Reading of current in ammeter = amperes.

Distance between centre of coil and centre of needle.	Deflection in Magnetometer								Mean θ	Tan θ	H Tan θ	Current calculated $\frac{10 (r^2 + d^2)^{3/2}}{2\pi n r^2} \times H$ $\times \tan \theta$ amperes
	East of coil				West of coil							
	Current direct		Current reversed		Current direct		Current reversed					
	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8				
Mean												

$\therefore$ Mean value of current = amperes.

Have similar tabular forms for readings taken for other values of current.

(B) Moment of a magnet

The above experiment can be modified for the determination of the moment of a magnet. Pass a steady current through the coil and get a suitable deflection (between 30° and 60°) in the magnetometer placed at a distance of d_1 cms. from the centre of the coil.

Place the given magnet on the other side of the magnetometer, with its axis along the axis of the coil and passing through the centre of the needle. Adjust its position and cancel the deflection produced in the magnetometer. Note the distance d' between the centre of the magnet and the centre of the magnetometer. Reverse the current in the coil and reverse the magnet end for end. Adjust its distance d'' , so that the deflection is again zero. Transfer the magnetometer and the magnet to the other side of the coil. Place the magnetometer at the same distance d_1 cms. from the centre of the coil. Find, as before, the distances d''' and d'''' of the magnet from the magnetometer for which the deflection is zero. Let the average of d' , d'' , d''' and d'''' be d_2 .

Change the distance d_1 and determine the corresponding average value of d_2 . Take two or three sets of readings.

Now, due to the current in the coil, the intensity F_1 at the centre of the needle is given by

$$F_1 = \frac{2\pi nr^2 C}{10 (r^2 + d_1^2)^{3/2}}$$

Due to the magnet (in its end-on-position) the intensity F_2 at the centre of the needle is given by,

$$F_2 = \frac{2Md_2}{(d_2^2 - l^2)^2}$$

Since the resultant deflection is zero,

$$F_1 = F_2.$$

$$\therefore \frac{2Md_2}{(d_2^2 - l^2)^2} = \frac{2\pi nr^2 C}{10 (r^2 + d_1^2)^{3/2}}$$

$$\therefore M = \frac{\pi nr^2 C}{10 (r^2 + d_1^2)^{3/2}} \times \frac{(d_2^2 - l^2)^2}{d_2}$$

From the known values of n , r , d_1 , C , d_2 and l , calculate M .

Tabulate the results as follows :—

Number of turns of coil =
Radius of coil = cms.
Current in ammeter = amperes.
Length of magnet = cms.

Distance between centre of coil and centre of magnetometer d_1	Distance between centre of magnet and centre of magnetometer for nil deflection .				$M = \frac{\pi n r^2 C}{10 (r^2 + d_1^2)^{3/2}} \times \frac{(d_2^2 - l^2)^2}{d_2}$	
	Magnetometer East of coil		Magnetometer West of coil			Mean d_2
	d'	d''	d'''	d''''		
	Mean					

$\therefore$ Mean magnetic moment of the magnet } =

EXPERIMENT 77

FIELD ALONG THE AXIS OF A COIL CARRYING CURRENT—VIBRATION MAGNETOMETER

Aim :—To measure the magnetic intensity along the axis of a coil carrying current using a vibration magnetometer and calculate the current.

Apparatus required :—Field along axis of coil apparatus, vibration magnetometer, two or three accumulators, ammeter, rheostat, commutator, plug key, stop-watch.

Description of apparatus :—The same apparatus as was used in experiment 76 is used here. The deflection magnetometer is replaced by a Searle's vibration magnetometer. It is placed on the platform with the centre of the needle in the same horizontal plane as the centre of the coil.

Procedure :—Connect up, as in the previous experiment, the battery of two or three accumulators, the plug key, the ammeter, and the rheostat in series with the coil through the commutator.

Turn the coil, so that its plane is *perpendicular* to the magnetic meridian, ascertained by using a compass needle. Do not keep the ammeter or the rheostat near the coil. Place the vibration magnetometer on the platform. Adjust it suitably, so that the centre of the vibrating needle lies on the axis of the coil, at a distance of, say, 5 cms. from the centre of the coil.

See that there is no torsion in the suspension fibre and the magnetic needle points true north and south. Make a mark on the side of the beaker to indicate the equilibrium position.

Slowly bring another magnet near it, set the needle in vibration through a small arc and take it off. Omit the first few oscillations. Start the stop-watch when the needle passes through the equilibrium position and note the time for about 20 oscillations. Take two or three readings. Find the mean time and calculate the period of oscillation. Let it be T_0 . It is the period of oscillation in the earth's field alone.

Close the circuit. Adjust the rheostat so that the current passing through the circuit is 1 ampere as indicated by the ammeter. Set the needle of the magnetometer in vibration as before. Find the time for 20 oscillations. Take two or three readings and from the mean time, calculate the period T_1 . If T_1 is *less* than T_0 , it means that the magnetic intensity F at the centre of the needle due to the current in the coil is in the *same direction* as H . The resultant intensity will then be $(F + H)$. If T_1 is *greater* than T_0 , F and H are in *opposite directions*. The resultant intensity will then be $(F - H)$ or $(H - F)$.

Reverse the current in the coil. Wait till the needle comes to rest. Set it in vibration. Note the time for 20 oscillations. Take two or three readings and from the mean time calculate the period. Let it be T' .

Move the vibration magnetometer along the axis of the coil. Adjust its position, so that the distance between the centre of the needle and the centre of the coil is 10 cms. As before, find the period of oscillation. Let it be T_2 . Reverse the current and find the period of oscillation. Let it be T'' .

Determine likewise the periods T_3 , T''' , T_4 , T'''' , etc., when the distance is increased to 15 cms, 20 cms, etc.

Transfer the magnetometer to the other side of the coil. Place it at the same distances from the centre of the coil. Find the periods of oscillation for each position. Reverse the current in each case and find the period of oscillation.

Note the number of turns in the coil. Measure the radius of the coil accurately.

Theory :—If T_1 is less than T_0 , the intensity F due to current in coil is in the same direction as H .

Now,

$$H \propto \frac{1}{T_0^2} \text{ and } (F + H) \propto \frac{1}{T_1^2}$$

$$\therefore \frac{F + H}{H} = \frac{T_0^2}{T_1^2}$$

$$\therefore \frac{F}{H} = \frac{T_0^2 - T_1^2}{T_1^2}$$

$$\therefore F = H \frac{T_0^2 - T_1^2}{T_1^2}$$

$$\text{But } F = \frac{2\pi n r^2 C}{10 (r^2 + d^2)^{3/2}}$$

where r is the radius of the coil, n , number of turns in it, C , the current passing through it and d , the distance between the centre of the coil and the centre of the needle.

$$\therefore \frac{2\pi n r^2 C}{10 (r^2 + d^2)^{3/2}} = H \frac{(T_0^2 - T_1^2)}{T_1^2}$$

$$\therefore C = \frac{10 (r^2 + d^2)^{3/2}}{2\pi n r^2} \times \frac{H (T_0^2 - T_1^2)}{T_1^2} \text{ in amperes.}$$

From the known values of r , n , d , H , T_0 , T_1 , the current C in amperes can be calculated.

If T_1 is greater than T_0 , F and H are in opposite directions. The resultant intensity is $(F - H)$ or $(H - F)$ depending on whether F is greater than H or vice versa. Let F be greater than H .

$$H \propto \frac{1}{T_0^2} \text{ and } (F - H) \propto \frac{1}{T_1^2}$$

$$\therefore \frac{F - H}{H} = \frac{T_0^2}{T_1^2}$$

$$\therefore \frac{F}{H} = \frac{T_0^2 + T_1^2}{T_1^2}$$

$$\therefore F = \frac{H(T_0^2 + T_1^2)}{T_1^2}$$

$$\text{Now, } F = \frac{2\pi nr^2 C}{10(r^2 + d^2)^{3/2}}$$

$$\therefore \frac{2\pi nr^2 C}{10(r^2 + d^2)^{3/2}} = \frac{H(T_0^2 + T_1^2)}{T_1^2}$$

$$\therefore C = \frac{10(r^2 + d^2)^{3/2}}{2\pi nr^2} \times \frac{H(T_0^2 + T_1^2)}{T_1^2} \text{ in amperes.}$$

From the known values of r , d , n , H , T_0 and T_1 , C can be calculated in amperes.

Tabulate the results as follows :—

I. Period of oscillation in Earth's field.

Time for 20 oscillations				Period T_0
1	2	3	Mean	

II. Period of oscillation when placed along axis of coil carrying current.

(1) Period less than T_0

Ammeter reading	Distance from centre of coil to centre of needle d	Time for 20 oscillations						Period of oscillation T_1	Current calculated $10 \times \frac{(r^2 + d^2)^{3/2}}{2\pi nr^2} \times \frac{H(T_0^2 - T_1^2)}{T_1^2}$
		Magnetometer North of coil			Magnetometer South of coil				
		1	2	Mean	1	2	Mean		

(2) Period greater than T_0

Ammeter reading	Distance between centre of coil and centre of needle	Time for 20 oscillations						Period T_1	Current calculated $\frac{10 (r^2 + d^2)^{3/2}}{2\pi nr^2} \times H \frac{(T_1^2 + T_0^2)}{T_1^2}$
		Magnetometer North of coil			Magnetometer South of coil				
		1	2	Mean	1	2	Mean		

Note :—When F and H are opposite in direction, the resultant intensity is $(F - H)$. When $F = H$, you get the null point. At

that point, the period of oscillation will be infinity. For points between the null point and the coil, the resultant intensity is $(F - H)$. The formula already derived can be used.

For points beyond the null point, the resultant intensity is $(H - F)$. Now,

$$H \propto \frac{1}{T_0^2} \text{ and } (H - F) \propto \frac{1}{T_1^2}$$

$$\therefore \frac{H - F}{H} = \frac{T_0^2}{T_1^2}$$

$$\therefore \frac{F}{H} = \frac{T_1^2 - T_0^2}{T_1^2}$$

$$\therefore F = \frac{T_1^2 - T_0^2}{T_1^2} \times H$$

So, modify the other formula accordingly.

EXPERIMENT 78

ELECTRO-CHEMICAL EQUIVALENT OF COPPER

Aim :—To determine the electro-chemical equivalent of copper using the copper voltameter.

Apparatus required :—Accumulator, copper voltameter, tangent galvanometer, rheostat, commutator, plug-key, stop-clock.

Description of apparatus :—The copper voltameter, in its simple form, consists of a glass jar, with a lid of wood or any other non-conducting material. Three copper plates, about 10 cms. $\times$ 10 cms. each, are suspended from the lid, separated from each other by about 2 to 3 cms. The two outer plates are connected together and to a terminal fixed on the top of the lid. The inner plate is connected to another terminal on the lid. Copper sulphate solution slightly acidified with H_2SO_4 , sufficient to cover the plates, is kept in the jar.

Procedure :—Connect up the accumulator, the plug key, the copper voltameter and the rheostat in series with the tangent galvanometer through the commutator.

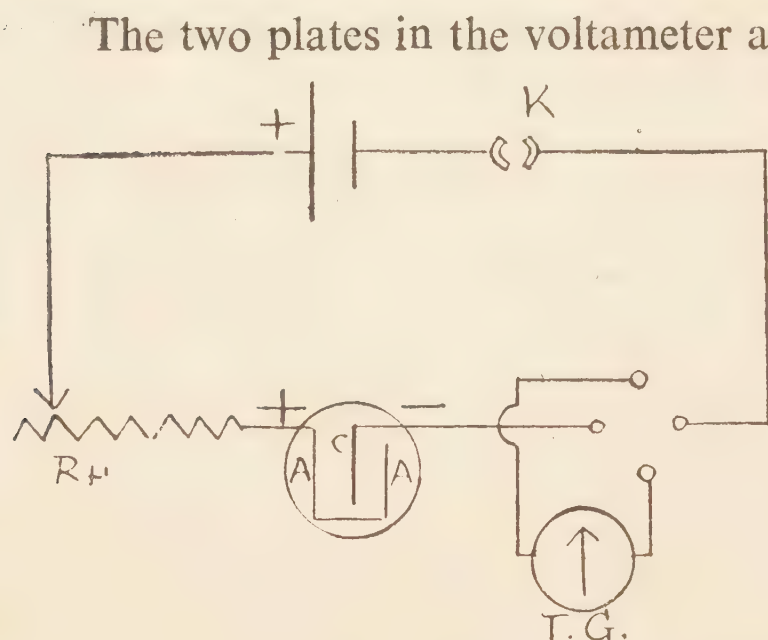


Fig. 176

The two plates in the voltameter are connected to the positive terminal of the battery, so that they form the Anode, while the single plate forms the Cathode.

Keep the rheostat at a distance from the tangent galvanometer. Adjust the coil of the tangent galvanometer so as to be in the magnetic meridian. Rotate the

magnetometer, so that the aluminium pointer reads zero, zero.

Use the five or ten turn coil of the galvanometer. Close the circuit. Adjust the rheostat, so that the deflection is about 45° . [To get a uniform, firm deposit of copper, the current density must not be greater than 1 ampere for 50 sq. cms. of area of plate immersed in the solution. With a 10 turn coil, the current will be about $\frac{1}{2}$ an ampere corresponding to a deflection of 45° . If a 5 or 10 turn coil is not available, use the 50 turn coil. But, for the same deflection, the current will be only about $\frac{1}{10}$ of an ampere. So, to get a good deposit, the current will have to be passed for a longer time.]

Having adjusted the current, break the circuit. Remove the inner plate forming the cathode. Wash and dry it. Polish its surface with a bit of fine sand paper.

Find its weight accurately, correct to three places of decimals. Re-insert it into the voltameter.

Close the circuit and start a stop-clock. Note the deflections at both ends of the pointer, when steady. At the end of every five minutes, reverse the current in the tangent galvanometer by means

of the commutator and note the deflections. After passing the current for 30 minutes, break the circuit. Note the exact time for which the current was passed. Remove the inner plate, wash it well in a gentle stream of running water from a tap. Dry it under a fan or by pouring on it a few drops of spirit. When dry, find its weight again accurately, correct to three places of decimals. The excess of weight represents weight of copper deposited. Repeat the experiment and take one more set of readings, if possible. Measure accurately the radius of the galvanometer. Note the number of turns of coil used.

Theory :—When a current of C amperes passes through a copper voltameter for t seconds, the mass m of copper deposited is given by,

$$m = e \times C \times t$$

where e is the electro-chemical equivalent of copper.

The current C , as indicated by the tangent galvanometer, is given by,

$$C = \frac{10 r H}{2 \pi n} \tan \theta$$

where r is the radius of the coil, n the number of turns in the coil, H the horizontal component of the earth's field and θ the mean deflection.

Tabulate the results as follows :—

I. Number of turns of coil used	= 6
Mean radius of the coil	= 7.7 cms.
Time of passage of current	= 30 minutes.
Mean deflection in the tangent galvanometer	= 43.5°.
Horizontal component of the Earth's field	= 0.38 gauss.

$$\therefore \text{Current } C \text{ in amperes} = \frac{10 \times 7.7 \times 0.38 \times \tan 43.5}{2 \times 3.1416 \times 6} = 0.74 \text{ amperes.}$$

II. Weight of copper deposited.

Load on pan		Turning points		Resting point	Weight correct to three places of decimals
Left	Right	Left	Right		
0	0	9.0 9.0	11.0	10.0	...
Copper plate before deposit	103.540	8.0 8.0	12.0	10.0	103.540 grams
Copper plate with deposit	103.990	10.0 10.0	15.0	12.5	103.998 grams
	104.000	8.0 8.0	11.0	9.5	

$\therefore$ Deposit of copper = 0.458 grams.

$$\therefore \text{Electro-chemical equivalent of copper} \left. \vphantom{\begin{matrix} \text{Electro-chemical} \\ \text{of copper} \end{matrix}} \right\} = \frac{0.458}{0.74 \times 1800}$$

$$= 0.000345 \text{ grams per coulomb.}$$

(The E.C.E. of copper is actually 0.0003295 grams per coulomb).

EXPERIMENT 79

METRE BRIDGE—SPECIFIC RESISTANCE

Aim :—To determine the resistance of a coil of wire using the metre bridge and calculate the specific resistance of the material of the wire.

Apparatus required :—Metre bridge, Lechlanche's cell, a resistance box (0 to 50 ohms), a coil of wire of known resistance, a sensitive pointer galvanometer, safety resistance, coil of wire, contact maker or jockey, plug key, screw gauge.

Description of apparatus:—The metre bridge (or Wheatstone's bridge) consists of a base board of wood with a uniform wire of platinoid or constantan or german silver, one metre long stretched over it. The two ends of the wire are soldered to two thick L shaped copper strips A and B. In between the other ends of these two strips, there is another similar copper strip C. The three copper strips

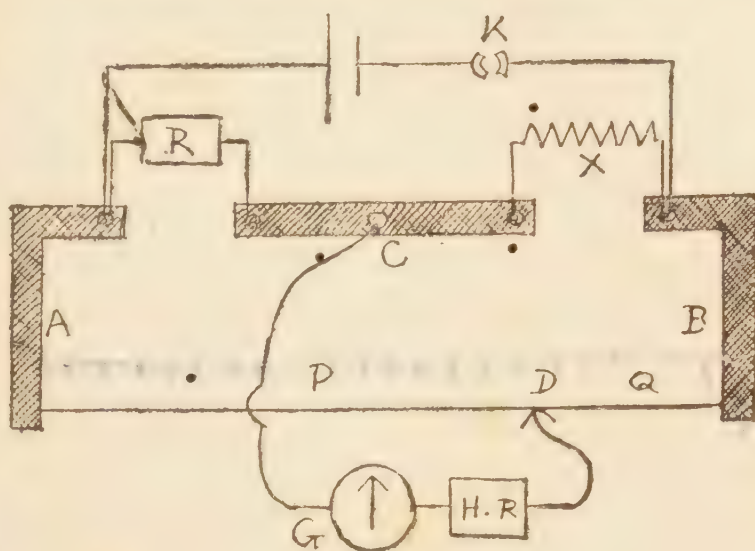


Fig. 177

are fixed on the board. A metre scale is fitted by the side of the wire. The three copper strips have terminals fixed to them.

Procedure:—Connect the resistance box R in the gap between the copper strips A and C. In the other gap between C and B, connect the coil of wire X whose resistance is to be determined.

Connect the terminals of the Leclanche's cell to A and B, introducing the plug key K between B and the cell. Connect the terminals of the galvanometer to C and the contact-maker (jockey), introducing the high resistance between C and the galvanometer G. Unplug a resistance R of the order of the unknown resistance, from the resistance box.

Close the circuit. The high resistance has generally a plug in it. If the plug is removed, the resistance is included in the circuit. If it is inserted, the resistance is cut out. Remove the plug. Touch one end of the wire with the contact-maker momentarily. Note the direction of deflection of the pointer in the galvanometer. Touch the other end of the wire with the contact-maker. Note the direction of deflection. [These must be on opposite sides of the zero. Otherwise, the connections are wrong.] Touch the wire at intermediate points, and locate the point where, if the wire is touched, the galvanometer shows zero deflection. Cut out the high resistance and find the exact balance point D. This point must be about the middle of the wire. [Do not slide the contact-maker over the wire. If you do so, its uniform cross-section will

be affected.] Carefully measure the distances of the balance point from the ends of the wire. Let them be l_1 and $(100 - l_1)$, since the length of the wire is 100 cms.

Interchange the resistance box and the coil of wire and find the balance point again. Measure the distances l_2 and $(100 - l_2)$ from the ends of the wire.

Change the resistance in the box and repeat the experiment. Take readings for three or four different values of the resistance in the box. See that the balance point is not far from the middle of the wire.

Remove the coil of wire, stretch it, so that there are no kinks in it and measure its length accurately. Make due allowance for the lengths of the wire under the terminals, used for connecting it.

Find the diameter of the wire at half a dozen places using the screw gauge. At each place, find the diameter, in two perpendicular directions. Take the mean of the readings and calculate the radius.

Theory :—The resistance in the box R , the unknown resistance X and the two parts of the wire P and Q on either side of the balance point form a Wheatstone's net. When the galvanometer shows ~~nil~~ deflection,

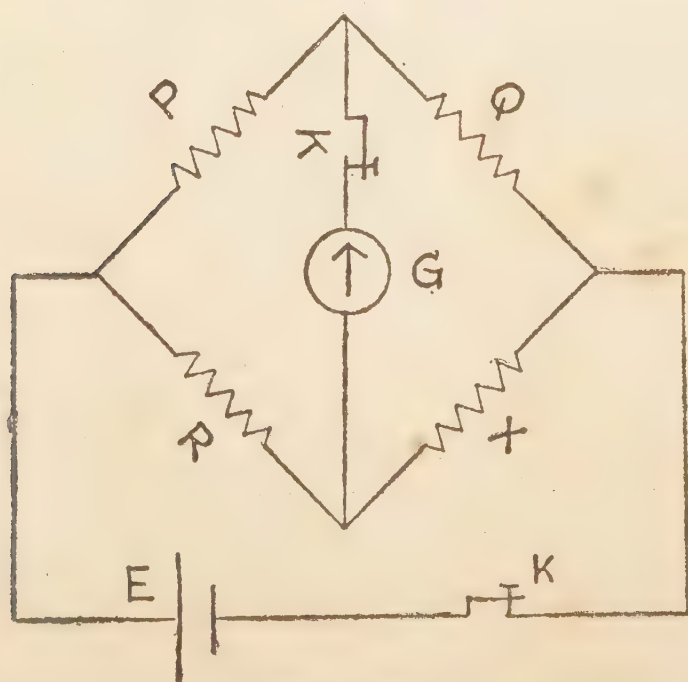


Fig. 178

$$\frac{P}{Q} = \frac{R}{X} \quad \text{or} \quad X = R \times \frac{Q}{P}.$$

The wire is uniform in cross-section. So,

$$\frac{Q}{P} = \frac{(100 - l_1)}{l_1}$$

$$\therefore X = R \times \frac{(100 - l_1)}{l_1}$$

From the known values of R , l_1 and $(100 - l_1)$, X can be calculated. Again, if the specific resistance of the wire is ρ , its length L and mean radius r ,

$$X = \frac{\rho \times L}{\pi r^2}$$

$$\therefore \rho = \frac{\pi r^2 X}{L}$$

From the known values of X , r and L , ρ can be calculated.

Tabulate the results as follows :—

I

Known Resistance R ohms.	Balancing lengths before inter-changing		Unknown Resistance $X = R$ $\times \left(\frac{100 - l_1}{l_1} \right)$ ohms.	Balancing lengths after inter-changing		Unknown Resistance $X = R$ $\times \left(\frac{100 - l_2}{l_2} \right)$ ohms.
	l_1 cms.	$(100 - l_1)$ cms.		l_2 cms.	$(100 - l_2)$ cms.	
2.0	51.0	49.0	1.92	49.0	51.0	1.92
5.0	71.7	28.3	1.97	28.2	71.8	1.97

$\therefore$ Mean value of $X = 1.95$ ohms.

[Note :— l_1 and l_2 are the lengths measured from the same end of the wire, say, left hand end.]

II Length of wire = 97 cms.

Mean diameter of wire = 0.056 cms.

$\therefore$ Mean radius of wire = 0.028 cms.

$$\therefore \rho \text{ (Eureka)} = \frac{3.1416 \times (0.028)^2 \times 1.95}{97}$$

$$= 49.5 \times 10^{-6} \text{ ohms per cm. cube.}$$

EXPERIMENT 80

POST OFFICE BOX—SPECIFIC RESISTANCE

Aim :—To determine the resistance of a coil of wire using the Post Office Box and to calculate its specific resistance.

Apparatus required :—Post office box, coil of wire of unknown resistance, Lechlanche's cell, sensitive pointer galvanometer, safety high resistance, screw gauge.

Description of apparatus :—The Post office box has incorporated in it a compact arrangement of three groups of resistances, say, P, Q and R. The two groups P and Q have in them, resistances, 10, 100 and 1000 ohms. They are known as the ratio arms. The third group R has resistances ranging from 1 to 5000 ohms. In this arm, any resistance from 1 to 11110 ohms can be obtained by

removing the appropriate plugs. Along with another resistance S , you can form a Wheatstone's net, P , Q , R and S forming its

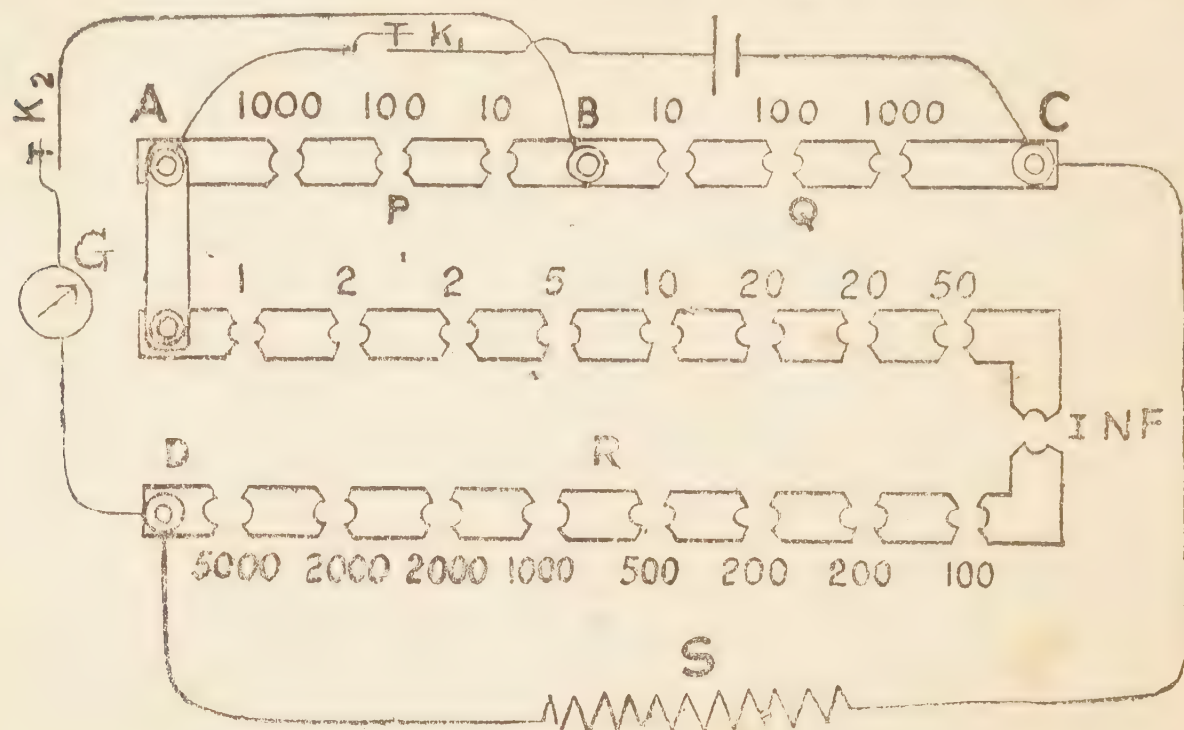


Fig. 179

four arms. At the junctions between P and Q , P and R and at the ends of Q and R , terminals are fitted up. Two tap keys K_1 and K_2 are incorporated in the box for inclusion in the battery and galvanometer circuits.

Procedure :—Connect the ends of the unknown resistance S to the terminals at the free ends of Q and R . Let the junctions between R and P , P and Q , Q and S , S and R be respectively A , B , C , D . Usually, one end of one of the tap keys K_1 is connected to A and one end of the other K_2 to B .

Connect the terminals of a Leclanche's cell to C and A , through the tap key K_1 . Connect the terminals of the sensitive galvanometer through the safety high resistance to B and D , through the tap key K_2 .

Unplug 10 and 10 in the ratio arms P and Q . Unplug the high resistance (safety). Press the tap key K_1 in the battery circuit and then the tap key K_2 in the galvanometer circuit. Note the direction of deflection. Unplug the infinity plug in the third arm R . Press K_1 and K_2 and note the direction of deflection. If the connections are in order, the two deflections will be on opposite sides.

Note :—A common defect in plug type resistance boxes is that all the plugs may not be tightly sitting in the sockets. If there is a loose contact between a plug and the socket, that resistance gets included in the circuit without your knowledge. So, press tightly with a clock-wise screw motion all the plug every time you are noting a deflection.

Unplug a resistance, higher than S , in the arm R. Press K_1 and K_2 and note the deflection. Unplug a small resistance and note the deflection. Find two resistances, differing by 1 ohm, for which the deflections are on opposite sides of zero position. Cut out the safety resistance, if necessary, while you are taking the final reading.

Next, unplug 100 ohms in the arm P and 10 ohms in the arm Q. As before, find two resistances in the arm R, differing by 1 ohm, for which the deflections are on opposite sides of zero. These resistances will be roughly 10 times more than the resistances previously found.

Unplug 1000 in the arm P and 10 in the arm Q. Again, find two resistances in R, differing by 1 ohm for which the deflections are on opposite sides. These resistances will be about 100 times more than the resistances obtained, when the resistances unplugged in P and Q were 10 and 10.

For this part of the experiment, unless the galvanometer is sensitive enough, an appreciable deflection will not be produced. The safety high resistance may not even be necessary. From the deflections on either side of zero, estimate the actual resistance for which the deflection will be zero.

If P, Q, R and S are the four resistances forming the Wheatstone's net,

$$\frac{P}{Q} = \frac{R}{S}$$

when there is balance. When P and Q are each equal to 10 ohms, $R = S$. When $P = 100$ ohms and $Q = 10$ ohms, $R = 10 S$. When $P = 1000$ ohms and $Q = 10$ ohms, $R = 100 S$.

So, from the value of R obtained in the third part of the experiment, S can be calculated.

$$S = \frac{R}{100} \text{ ohms}$$

Remove the coil of wire. Stretch it without kinks in it and measure its length L accurately.

With a screw gauge, measure the diameter of the wire, at about six places on it and at each place in two perpendicular directions. Find the mean diameter and calculate the radius r of the wire.

The specific resistance ρ of the wire is given by the formula,

$$\rho = \frac{\pi r^2 X}{L}$$

where X is the resistance of the wire.

Tabulate the results as follows :—

Resistance unplugged				Unknown resistance X ohms
in arm P	in arm Q	in arm R		
		Deflection Left	Deflection Right	
ohms	ohms	ohms	ohms	
10	10	2	1	Between 1 & 2
100	10	20	19	„ 19 & 20
1000	10	194	193	„ 193 & 194

$\therefore$ Unknown Resistance = 1.935 ohms.

Length of wire = 97 cms.

Mean diameter of wire = 0.056 cms.

$\therefore$ Mean radius of wire = 0.028 cms.

$$\therefore \rho \text{ (Eureka)} = \frac{3.1416 \times (0.028)^2 \times 1.935}{97}$$

$$= 49.15 \times 10^{-6} \text{ ohms per cm. cube.}$$

EXPERIMENT 81

CAREY-FOSTER BRIDGE

Aim :—(1) To compare two nearly equal resistances using the Carey-Foster Bridge and (2) to find the end resistances in it.

Apparatus required :—Carey-Foster Bridge, two equal resistances (or two resistance boxes, 0—50 ohms), two *nearly* equal resistances, a standard 1 ohm (or 0.5 ohm) resistance, Lechlanche's cell, sensitive pointer galvanometer, contact maker, plug key.

Description of apparatus :—The Carey-Foster Bridge is a modified form of the metre bridge. The ends of a uniform wire of

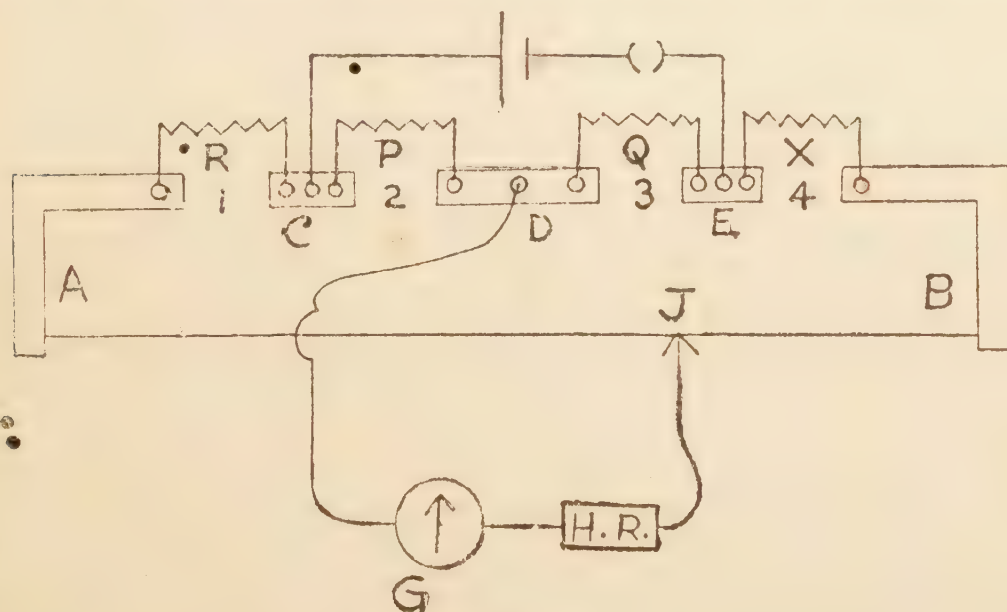


Fig. 180

constantan or german silver, 1 metre in length, are soldered to two L shaped thick copper strips A and B. In between the other ends of A and B, there are three similar copper strips C, D and E, there being four gaps 1, 2, 3 and 4 in all, between the copper strips. All these are fitted on a base-board of wood. Terminals are provided at each end of the copper strips. A metre scale is fitted on the board by the side of the wire.

Procedure :—The two equal resistances P and Q, and the two *nearly* equal resistances R and S must be of the same order.

First, connect up P and Q in the two inner gaps, 2 and 3. In gap 1, connect a thick copper plate. Connect the standard one ohm resistance in gap 4. Connect the terminals of the Lechlanche's cell to the terminals on the copper strips C and E,

including the plug key in the circuit. Connect one terminal of the galvanometer to the terminal on the central strip D. Connect the other terminal to the contact meter J, including the high resistance in the circuit.

Close the circuit. Unplug the high resistance in the galvanometer circuit. Place the contact maker at the end of the wire nearer to the standard one ohm. Find the balance point for nil deflection in the galvanometer. Cut out the high resistance and find the balance point again accurately. Note the reading on the scale.

Inter-change the copper plate and the standard one ohm resistance in gaps 1 and 4. Again, find the balance point. It will now be near the other end of the wire. Note the reading. Find the difference in length between the two readings. Let it be L .

The resistance of L cms. of wire is 1 ohm. So, the resistance per cm. length of wire is $\frac{1}{L}$ ohms per cm. Let it be ρ .

Remove the copper plate and the standard resistance from the gaps 1 and 4. Connect the two nearly equal resistances R and S in the gaps.

Find the balance point first approximately. Cut out the high resistance and find it accurately. Inter-change the two resistances R and S . Again find the balance point. Find the difference in length between the two. Let it be l . Then, the difference between the resistances R and S is equal to $l \times \rho$.

The difference between the two resistances must be less than the resistance of the whole wire. Otherwise, no balance point will be got on the wire.

Theory :—Let the lengths of the wire, when balance is obtained be l_1 and $(100-l_1)$, l_1 being the length, say, on the left-hand side. After inter-changing, let the balancing lengths be l_2 and $(100-l_2)$, l_2 being the length on the left-hand side. Then, before inter-changing,

$$\frac{P}{Q} = \frac{R + l_1 \rho}{S + (100-l_1) \rho}$$

$$\therefore \frac{P}{P + Q} = \frac{R + l_1 \rho}{R + S + 100 \rho}$$

After inter-changing,

$$\frac{P}{Q} = \frac{S + l_2 \rho}{R + (100 - l_2) \rho}$$

$$\therefore \frac{P}{P + Q} = \frac{S + l_2 \rho}{R + S + 100 \rho}$$

Hence, $R + l_1 \rho = S + l_2 \rho$.

$$\therefore (R - S) = (l_2 - l_1) \rho.$$

The balance point will always be nearer to the larger among the two resistances R and S .

Tabulate the results as follows :—

I

Resistance		Balancing length		$\rho = \frac{(R-S)}{(l_2-l_1)}$
R ohms	S ohms	Before inter- changing l_1 cms.	After inter- changing l_2 cms.	
1	0			

$\therefore$ Resistance per cm. length of wire = ohms

II

Resistance		Balancing length		$(R-S) = (l_2-l_1) \rho$ ohms
R ohms	S ohms	Before inter- changing l_1 cms.	After inter- changing l_2 cms.	

$(R - S) =$ ohms

If one of them is known, the other can be calculated.

Note :—The standard resistance used for determining the resistance per cm. length of wire will depend on the resistance of the wire. It may be 0.1 ohm, 0.5 ohm, 1 ohm. Or a fractional box may be used.

End resistances in Carey-Foster bridge

Procedure :—For very accurate measurements of resistances with the Carey-Foster bridge, the resistances at the ends of the wire must be determined. In the outer gaps 1 and 4, two thick copper plates are connected. P is made an exact multiple of Q . Let the ratio be n . The balancing lengths l_1 and $(100 - l_1)$ are obtained. P and Q are inter-changed and the balancing lengths determined. Let them be l_2 and $(100 - l_2)$. Let l_1 and l_2 be measured from the left-hand end. Let λ_1 and λ_2 be the end resistances expressed in terms of the length of wire at the left and at the right.

Then, for the first balance point,

$$\frac{P}{Q} = \frac{\lambda_1 + l_1}{\lambda_2 + (100 - l_1)} = n$$

For the second balance point,

$$\frac{Q}{P} = \frac{\lambda_1 + l_2}{\lambda_2 + (100 - l_2)} = \frac{1}{n}$$

$$\therefore \lambda_1 + l_1 = n \lambda_2 + n(100 - l_1)$$

$$\text{and } n \lambda_1 + n l_2 = \lambda_2 + (100 - l_2)$$

Solve these equations for λ_1 and λ_2 . You will get

$$\lambda_1 = \frac{l_1 - n l_2}{(n - 1)}$$

$$\text{and } \lambda_2 = \frac{n l_1 - l_2 + (n - 1) 100}{(n - 1)}$$

λ_1 must be added to lengths measured from the left hand end and λ_2 to lengths measured from the right hand end.

EXPERIMENT 82**TEMPERATURE COEFFICIENT OF RESISTANCE**

Aim :—To determine the temperature coefficient of resistance of a coil of wire.

Apparatus required :—Coil of wire whose temperature coefficient is to be determined, post office box, Lechlanche's cell, sensitive galvanometer, high resistance, water bath.

Description of apparatus :—The coil of wire is wound round a thick sheet of mica and kept immersed in some insulating oil in a

test-tube. Its ends are soldered to thick copper leads, with terminals at their ends. The test-tube is closed by a rubber stopper, with a hole through which a thermometer is inserted.

Procedure :—The test-tube with the resistance inside is immersed in a water bath. The resistance is connected to the post office box, so as to form the fourth arm of a Wheatstone's net. Connect the Lechlanche's cell and the galvanometer to alternate junctions. Include the high resistance in the galvanometer circuit.

Unplug 10 and 10 in the ratio arms. Test, if the connections are all right, by noting whether you get deflections on opposite sides, when the resistance in third arm is zero or infinity.

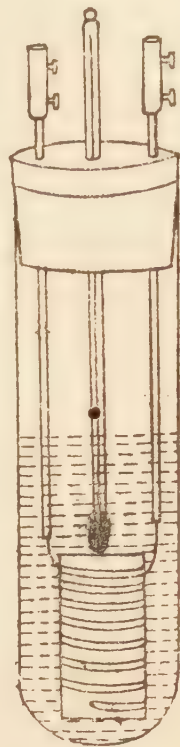


Fig. 181

Find the two resistances, differing by one ohm, to be unplugged in the arm R, so as to produce deflections on opposite sides. Unplug 100 and 10, and find the two resistances likewise. Then unplug 1000 and 10, and find the resistances. From this value, calculate the resistance of the coil, correct to three places of decimals. Note the temperature of the oil in the test tube.

Raise the temperature of the oil to, 50°C by heating the water bath. Keep it constant for about 15 minutes. The oil in which the coil is immersed is a bad conductor of heat. So, give sufficient time for the oil to be raised to a uniform temperature. Find the resistance of the coil, by the method indicated above.

Raise the temperature of the bath, so that the temperature of the oil rises to 75° . Wait for the temperature of the oil to be steady for about 15 minutes. Find the resistance of the coil correct to two places of decimals. Raise the water-bath to its boiling point. When the temperature of the oil is steady, find the resistance of the coil.

Cool the water bath, so that the temperature of the oil falls to 75°C , 50°C and the room temperature. At each temperature,

determine the resistance of the coil correct to two places of decimals.

If R_1 is the resistance of the coil at temperature $T_1^\circ\text{C}$, R_2 , the resistance at temperature $T_2^\circ\text{C}$ and R_0 , the resistance at 0°C

$$\begin{aligned} R_1 &= R_0 (1 + \alpha T_1) \\ R_2 &= R_0 (1 + \alpha T_2) \\ \therefore \frac{R_2}{R_1} &= \frac{1 + \alpha T_2}{1 + \alpha T_1} \\ \therefore \alpha &= \frac{R_2 - R_1}{R_2 \times T_1 - R_1 \times T_2} \end{aligned}$$

Calculate α for each pair of temperatures.

Note :—The change of resistance with temperature, is given by the equation,

$$R_1 = R_0 (1 + \alpha T_1 + \beta T_1^2)$$

where α and β are constants. But, ordinarily, β can be ignored as it is very small.

Tabulate the results as follows :

Temperature of oil	Resistance		Mean resistance	Coefficient of increase of resistance
	Temperature rising	Temperature falling		
Room temperature				
50°C				
75°C				
Boiling temperature of water-bath				
Mean ...				

For calculating the temperature coefficient, take the resistances at the room temperature and 75° , and the resistances at 50° and the boiling temperature of the water-bath.

Graph :—Draw a graph representing temperature along the Y axis and resistance along the X axis. You will get a straight line graph. From the graph, find the resistances of the coil at 0°C and 100°C and calculate the temperature coefficient.

EXPERIMENT 83

MECHANICAL EQUIVALENT OF HEAT ELECTRICAL METHOD

Aim :—To determine, by the electrical method, the mechanical equivalent of heat, using Joules' calorimeter.

Apparatus required :—Joules' calorimeter, ammeter, (0—5 amps.) voltmeter (0—10 volts) two or three accumulators, rheostat, plug key, stop-clock, sensitive thermometer.

Description of apparatus :—The Joules' calorimeter consists of a bright, polished calorimeter of copper or aluminum, covered by a lid of ebonite or other non-conducting material. Two terminals are fitted on it. Short thick copper leads are soldered to the bottom of the terminals. The ends of a coil of insulated wire of platinoid or constantan or manganin are soldered to the ends of the copper leads. The lid has a hole at the centre for introducing a thermometer reading $\frac{1}{10}^{\circ}\text{C}$ and a side hole for a stirrer. The calorimeter is suspended inside a large calorimeter which, in turn, is kept in a wooden box.

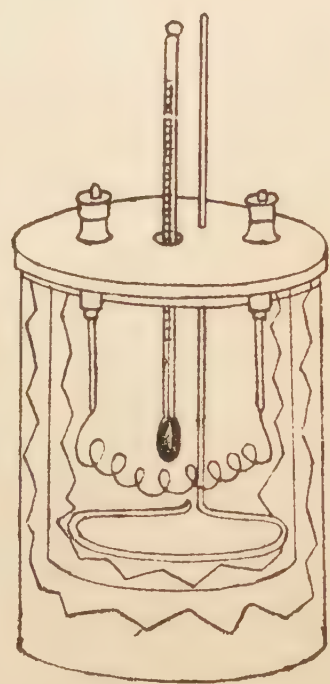


Fig. 182

Procedure :—Connect the battery of two or three accumulators, in series with the Joules calorimeter, ammeter, rheostat and the plug key. Connect the voltmeter in parallel with the coil of the Joule's

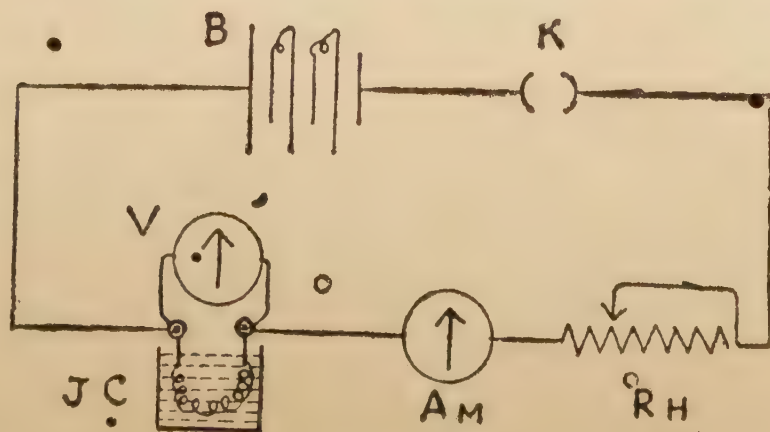


Fig. 183

calorimeter. The ammeter and voltmeter must have sufficient range and must read fractions of an ampere or volt respectively.

Perform a preliminary experiment for adjusting the current. Take water in the calorimeter sufficient to immerse the coil. Have the maximum resistance in the rheostat. Close the circuit. Adjust the rheostat, so that the current is about 1 to 2 amperes. Do not disturb the rheostat.

Break the circuit. Remove the calorimeter and throw out the water. Dry it and find its weight with the stirrer, correct to a centigram. Take sufficient water in it so as to immerse the coil. Find the weight again. Replace the coil in it.

Introduce the thermometer into the calorimeter. Stir the water well and note its initial temperature. Close the circuit and start the stop-clock simultaneously. Keep stirring the water continuously. Note the temperature of the water every 30 seconds. Note down the readings of the ammeter and the voltmeter. When the rise of temperature is about 5°C break the circuit. Note the time for which the current was passed. Stir the water well and note the maximum temperature reached. Allow the water to cool and continue noting the temperatures every half minute, till the temperature falls by about 1° or 2°C .

Draw a graph representing the time along X axis and the temperature along the Y axis. From the graph, find the radiation correction, adopting Barton's method.

Let a potential difference of E volts be applied to a resistance of R ohms. Let the current produced be C amperes. Let it pass through it for t seconds. Then, the quantity of heat produced Q , is given by,

$$Q = \frac{E C t}{J} \text{ calories}$$

$$= \frac{C^2 R t}{J} \text{ calories.}$$

Where J is the mechanical equivalent of heat. If the resistance is immersed in W grams of water kept in a calorimeter of

water equivalent w grams and the rise of temperature is $T^{\circ}\text{C}$, then,

$$Q = (W + w) T \text{ calories.}$$
$$\therefore \frac{E C t}{J} = (W + w) T$$
$$\therefore J = \frac{E C t}{(W + w) T} \text{ Joules per calorie.}$$

Note :—In the above experiment, the current may be measured using a tangent galvanometer and commutator. The resistance of the coil may be determined with a Post office box and the alternative formula, $\frac{C_2 R t}{J}$ used. Current may be passed from the mains using suitable lamp resistances.

Tabulate the results as follows :—

I

Weight of Calorimeter + stirrer =
Weight of Calorimeter + stirrer + water =

Time	Ammeter reading	Voltmeter reading	Temperature of water
------	-----------------	-------------------	----------------------

Mean value of current = amps
Mean value of potential difference = volts
Time of passage of current = seconds
Final temperature reached = $^{\circ}\text{C}$
Radiation correction from graph = $^{\circ}\text{C}$
Final corrected temperature = $^{\circ}\text{C}$
 $\therefore$ Rise of temperature = $^{\circ}\text{C}$

$$\therefore J = \frac{E C t}{(W + w) T} \text{ Joules per calorie.}$$

EXPERIMENT 84

POTENTIOMETER

COMPARISON OF E.M.Fs. OF CELLS—DETERMINATION OF INTERNAL RESISTANCES OF CELLS

Aim :—(1) To compare the Electro-motive forces of cells and (2) to determine their internal resistances, using the Potentiometer.

Apparatus required :—Potentiometer, accumulator, Daniel's cell, Lechlanche's cell, sensitive galvanometer, high resistance, resistance box, plug keys, double-pole double throw key, a low value rheostat.

Description of apparatus :—The common form of the wire potentiometer consists of ten uniform wires of platinoid or german silver or constantan, each one metre in length. They are stretched, parallel to each other, over a glass or milk glass

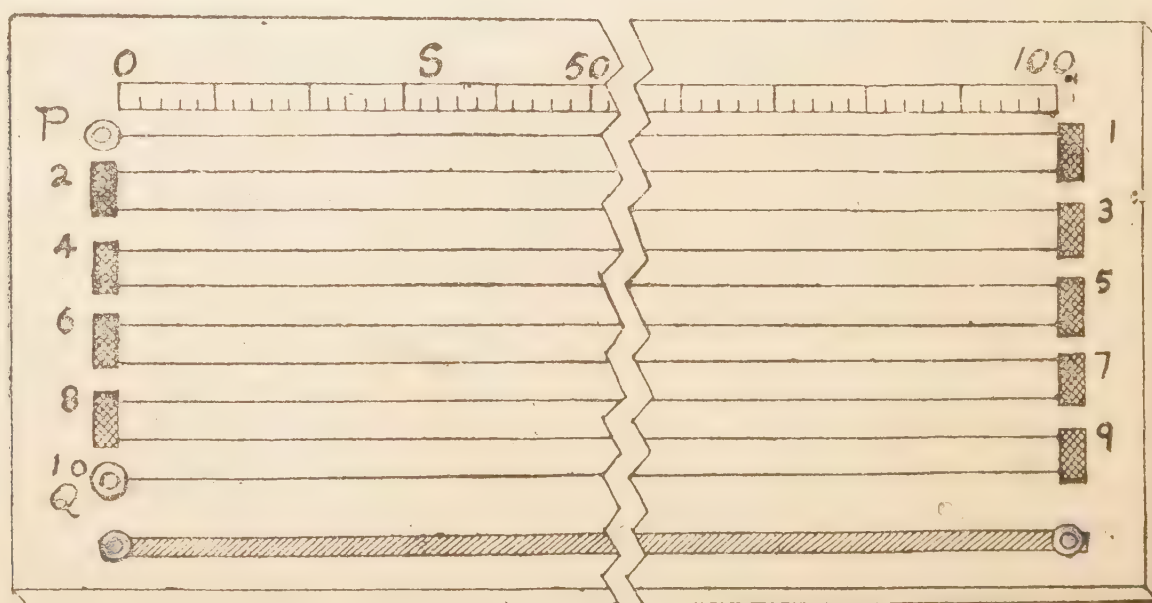


Fig. 184

plate, fitted on a base board of wood. They are all connected in series so as to form a continuous conductor from end to end. The ends of any two adjacent wires are soldered to small thick pieces of copper having nil resistance. The free end P of the first wire and the free end Q of the last wire are soldered to copper pieces on which terminals are fitted. The total length of wire between the two terminals is *exactly* 1000 cms. The wires need not, however, be separate pieces. A single wire of suitable

length may also be used from one end to the other with an effective length of 1000 cms. A metre scale *S* is fitted by the side of the first wire.

On a metallic jockey, sliding on the board, ten contact makers are fitted up, one for each of the wires. By pressing down any one of them, contact is made on the corresponding wire. The sliding jockey, resting on three metallic legs, moves over a long, thick strip of copper, as the jockey slides over the potentiometer. The copper strip is provided with terminals at either end. So, when any contact maker is pressed down to touch the wire, metallic connection gets established between the wire and the terminals on the copper strip.

The potentiometer is generally used for the accurate and satisfactory measurement of potential differences.

(A) Comparison of Electro-motive forces.

Procedure :—Connect the terminals of the accumulator to the ends of the potentiometer wire, including the plug-key and the rheostat in the circuit.

When the current is on, the P.D. applied to the terminals of the potentiometer is distributed over the length of the potentiometer wire. Since the wires are all of uniform cross-section, the potential gradient is uniform.

The fall of potential is the same for equal lengths of wire.

Connect *A*, one of the common terminals of the double-throw key, to the positive end *P* of the potentiometer wire. Connect *B*, the other common terminal, in series with the sensitive galvanometer, the high resistance and one of the terminals on the copper strip on which the jockey slides.

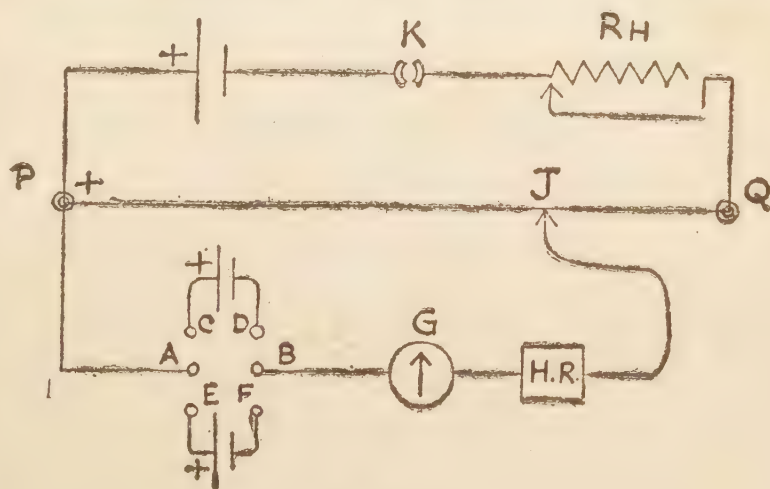


Fig. 185

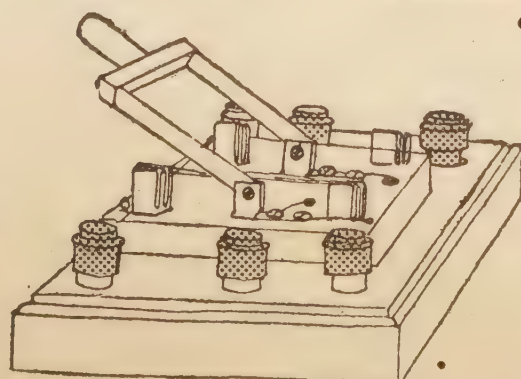


Fig. 186

Connect the terminals of the Lechlanche's cell to one pair of terminals C and D in the double-throw key and the terminals of the Daniel's cell, to the other pair of terminals E and F in the double-throw key. See that the positive terminals of the Lechlanche's cell and the Daniel's cell are respectively connected to the terminals C and E which are on the same side as A in the double-throw key.

Have zero resistance in the rheostat. Close the primary circuit of the accumulator. Using the double-throw key, either the Lechlanche's cell or the Daniel's cell can be included in the secondary circuit.

Unplug the high resistance. Keep the jockey at one end of the potentiometer. Close the secondary circuit with the Lechlanche's cell included in it. Press the contact maker on the first wire, near the positive end. Note the direction of deflection in the galvanometer. Press the contact maker at the end of the last wire. Note the direction of deflection. The deflections will be on opposite sides, if the connections are correct and the cells have been connected properly. Otherwise, they are faulty.

Having checked the correctness of the connections, move the jockey to the middle. Press the contact makers one by one and find the position of the balance point, for no deflection in the galvanometer. Cut out the high resistance and find the balance point accurately. Measure carefully the total length of wire L_1 from the positive terminal P in the potentiometer to the balance point. Manipulate the double-throw key to include the Daniel's cell in the secondary circuit. Find the balance point again. Measure the total length of wire L_2 from the positive terminal P to the balance point.

Alter the position of the sliding contact in the rheostat and include a small resistance in the primary circuit. Find the balance points corresponding to the Lechlanche's and the Daniel's cells. Measure the respective lengths.

Repeat the experiment changing the resistance in the primary circuit. Take five or six sets of readings.

Note :—In increasing the resistance in the primary circuit, care has to be taken to see that the potential difference between

the terminals of the wire due to the accumulator is always greater than the E.M.F. of the cell in the secondary circuit. If it becomes less, no balance will be obtained.

Calculations :—The accumulator maintains a constant difference of potential between the ends of the potentiometer wire. Let this be V volts. Then, the fall of potential per cm. is $\frac{V}{1000}$ volts per cm. This is constant. Let it be v . It is also uniform, as the wire is uniform.

A balance point is obtained, when the E.M.F. of the cell in the secondary circuit is equal to the potential difference between the positive terminal in the potentiometer and the balance point on the wire. Let this length be L . Then, the corresponding potential difference is $L \times v$. If the E.M.F. of the cell is E ,

$$\mathbf{E} = \mathbf{L} \times \mathbf{v}$$

Let E_1 and E_2 be the E.M.F.s of the Lechlanche's and Daniel's cells and let the corresponding balancing lengths be L_1 and L_2 respectively. Then,

$$\therefore \frac{E_1}{E_2} = \frac{L_1 \times v}{L_2 \times v} = \frac{L_1}{L_2}$$

If one of these E.M.F.s is known, the other can be calculated.

Tabulate the results as follows :—

Balancing length for		Ratio $\frac{L_1}{L_2}$
Lechlanche's cell L_1	Daniel's cell L_2	
Mean		

$\therefore$ The mean ratio between the E.M.F.s. of the }
Lechlanche's and Daniel's cell } =

Note :—If a standard cell (Weston cadmium or Clarke) is available, the absolute E.M.F. of the Leclanche's cell or Daniel's

cell can be determined, by the above method. In the absence of a standard cell, a freshly prepared Daniel's cell can be used instead. It gives a constant E.M.F. of 1.08 volts.

(B) Internal resistance of a cell

Procedure :—Connect the terminals of the accumulator to the ends of the potentiometer wire, including a rheostat and a plug key in the circuit. Connect the positive terminal of the Leclanche's cell, whose internal resistance is to be determined, to the positive end P of the potentiometer wire. Connect the negative terminal in series with the sensitive galvanometer, the high resistance and the jockey.

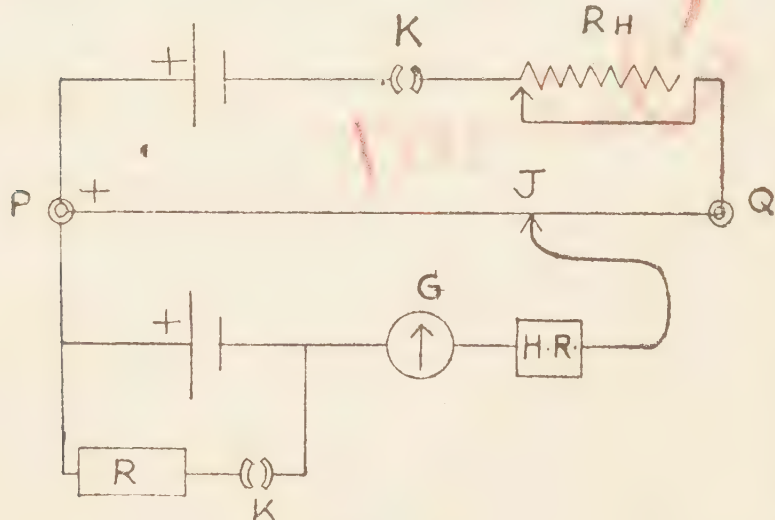


Fig. 187

Connect in parallel with the terminals of the Leclanche's cell, the resistance box and a plug key. Have zero resistance in the rheostat. Close the primary circuit. Remove the plug from the key in the resistance box circuit, so that the parallel circuit is open. Find the balancing length L for no deflection in the galvanometer, first with the high resistance unplugged and subsequently cut out.

Unplug a resistance of, say, 15 ohms in the box. Insert the plug and close the parallel circuit. Find the balancing length L_1 . Repeat the experiment unplugging 12, 10, 7, 5, and 2 ohms in the parallel circuit and find the corresponding balancing lengths.

Get another set of lengths, after increasing the resistance in the primary circuit and repeating the experiment.

Replace the Leclanche's cell by the Daniel's cell and repeat the experiment.

Calculations :—Let L be the balancing length, when the resistance in parallel with the Leclanche's or Daniel's cell is infinity

and L_1 , when the resistance is R . Let the internal resistance of the cell be r . Now, if the E.M.F. of the cell is E ,

$$E = L \times v.$$

When a resistance R is unplugged in the parallel circuit,

$$E = C (R + r) = CR + Cr.$$

CR is the P.D. between the terminals of the cell. This balances the P.D. corresponding to the length L_1 of the Potentiometer wire.

$$\therefore CR = L_1 \times v.$$

$$\therefore \frac{E}{CR} = \frac{L \times v}{L_1 \times v} = \frac{L}{L_1}$$

$$\therefore \frac{C(R + r)}{CR} = \frac{L}{L_1}$$

$$\therefore \frac{R + r}{R} = \frac{L}{L_1}$$

$$\therefore r = \frac{R \times (L - L_1)}{L_1}.$$

From the known values of R , L and L_1 , r can be calculated.

Tabulate the results as follows :—

I. Lechlanche's cell.

Balancing length for infinity resistance }
in parallel circuit } = L cms.

Resistance in parallel circuit R ohms	Balancing length L_1 cms.	Internal resistance $r = \frac{R \times (L - L_1)}{L_1}$

Enter the other results obtained similarly.

Note :—Begin with the largest resistance in the parallel circuit and then unplug resistances in the decreasing order. The internal resistance is not a constant. Its value is controlled by various factors. So, if you do not get consistent results, it may not entirely be due to faults in the experiment.

EXPERIMENT 85

POTENTIOMETER

COMPARISON OF RESISTANCES

Aim :—To compare two resistances using the potentiometer.

Apparatus required :—Potentiometer, two accumulators, two rheostats, the resistances to be compared, sensitive galvanometer, high resistance, two plug keys, a double-pole double-throw key.

Procedure :—Connect one of the accumulators in series with the potentiometer wire, a rheostat and a plug key. This forms

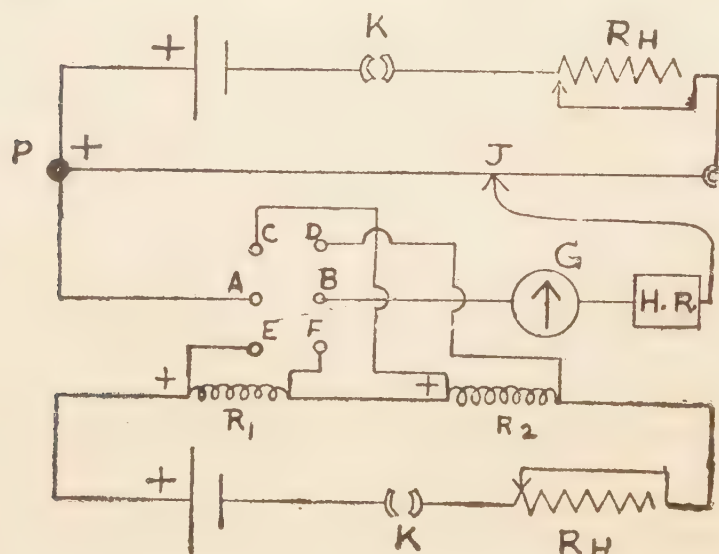


Fig. 188

the *primary* circuit. Connect the other accumulator in series with the two resistances to be compared, a rheostat and a plug key.

Connect one of the common terminals A of the double-throw key to the positive terminal P of the potentiometer. Connect the other terminal B through the

sensitive galvanometer and the high resistances to the jockey of the potentiometer.

Connect the ends of one of the resistances to be compared to one pair of terminals C and D of the double-throw key. Connect the ends of the other resistance to the other pair of terminals E and F in the key. By operating the double-throw key, one or the other of the resistances can be included in the *secondary* circuit of the potentiometer.

Note :—When a current passes through the resistances, a P.D. is developed in each of them. It is this P.D. that is to be found with the potentiometer. So, in connecting the ends of the resistances to the terminals in the double-throw key, sufficient care has to be taken. The terminal A is connected to the positive terminal

in the potentiometer. So, the terminals C and E must be connected to the ends of the resistances which are at the higher potential. If this is not done, the deflection in the galvanometer will always be in the same direction and a balance point will not be obtained.

Keep zero resistance in the rheostats and close the primary circuit and the circuit containing the resistances.

Unplug the high resistance. Include one of the resistances R_1 in the secondary circuit of the potentiometer. Find the balance point approximately first. Cut out the high resistance and find it accurately. Measure the length L_1 of the balance point from the positive terminal P of the potentiometer. Manipulate the double-throw key and include the resistance R_2 in the secondary circuit of the potentiometer. Find the balance point accurately. Measure its distance L_2 from the positive end P.

Adjust the rheostat in the primary circuit, so that a small resistance gets included in the circuit. Find the balancing lengths corresponding to R_1 and R_2 as before. Alter the resistance in the rheostat and repeat the experiment. Take half a dozen readings.

Adjust the resistance in the other rheostat and repeat the experiment. Take half a dozen readings.

Remember that the resistance in either rheostat must be altered every time, only after the readings of the balance points have been taken for both the resistances, under *identical* conditions.

Calculations :—The same current is passing through both the resistances. Let it be C . Then, the P.Ds. between the ends of R_1 and R_2 are CR_1 and CR_2 respectively. If the corresponding balancing lengths are L_1 and L_2 ,

$$\frac{C R_1}{C R_2} = \frac{L_1 \times v}{L_2 \times v}$$

where v is the fall of potential per cm on the potentiometer wire,

$$\therefore \frac{R_1}{R_2} = \frac{L_1}{L_2}$$

Tabulate the results as follows :—

Balancing Length		$\frac{R_1}{R_2} = \frac{L_1}{L_2}$
for Resistance R_1 L_1 cms.	for Resistance R_2 L_2 cms.	
Mean		

$$\therefore \text{Mean } \frac{R_1}{R_2} =$$

If one of the resistances is known, the other can be calculated from the above ratio.

EXPERIMENT 86

POTENTIOMETER

MEASUREMENT OF CURRENT AND CALIBRATION OF AMMETER

Aim :—(1) To measure current and determine the reduction factor of a tangent galvanometer and (2) to calibrate an ammeter.

(A) Measurement of a current and determination of the reduction factor of tangent galvanometer.

Apparatus required :—Potentiometer, two accumulators, a freshly prepared Daniel's cell, and a standard one ohm resistance, a tangent galvanometer, a commutator, a sensitive galvanometer, high resistance, two plug keys, a double-pole double-throw key, two rheostats.

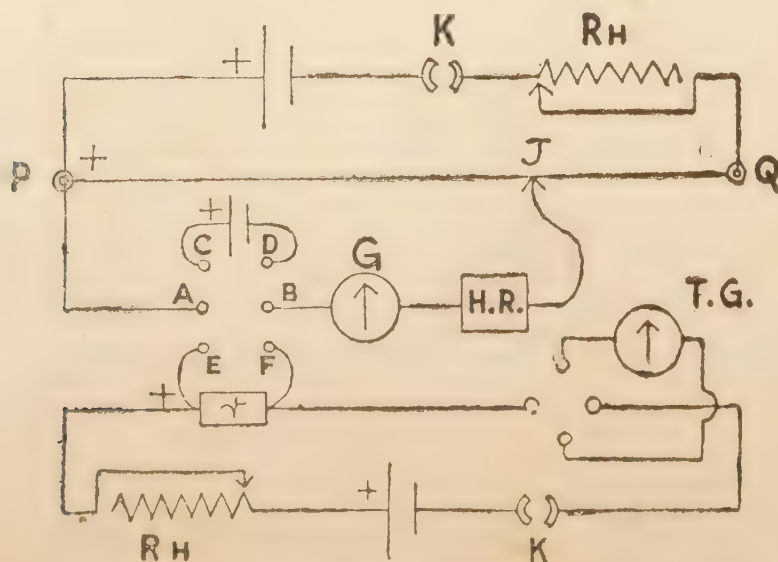


Fig. 189

Procedure :— Connect one of the accumulators to the two ends of the potentiometer wire through a plug key and a rheostat.

Connect in series with the other accumulator, the standard one ohm resistance r , the tangent galvanometer through the commutator, a rheostat and a plug key.

Connect one of the common terminals A of the double-throw key to the positive end P of the potentiometer wire.

Connect the other common terminal B in series with the galvanometer, the high resistance and the jockey.

Connect the Daniel's cell to one pair of terminals C & D in the double-throw key and the ends of the standard resistance to the other pair of terminals E & F. By manipulating the double-throw key, either the Daniel's cell or the standard resistance can be included in the secondary circuit of the potentiometer.

Note :—See that the positive terminal of the Daniel's cell and that end of the standard resistance which is at the higher potential are connected to the corresponding terminals C & E in the double-throw key.

Include the Daniel's cell in the secondary circuit of the potentiometer. Close the primary circuit. Have zero resistance in the rheostat. Unplug the high resistance and find the balance point approximately. Cut out the high resistance and find the balance point accurately. Measure carefully the balancing length. Let it be L cms. If the E.M.F. of the freshly prepared Daniel's cell is E , the fall of potential per cm. length of the potentiometer wire is $\frac{E}{L}$ volts per cm.

Close the circuit containing the standard resistance and tangent galvanometer. Use the 5 or 10 turn coil of the tangent galvanometer. Adjust the rheostat, so that the deflection is 40° .

By operating the double-throw key, include the standard resistance in the secondary circuit of the potentiometer. Find the balance point corresponding to the P.D. between the terminals of the standard resistance, first approximately and then accurately. Measure the balancing length L_1 carefully. Reverse the current in the tangent galvanometer and note the deflection. Every time note the readings at both ends of the pointer. Find the average deflection θ .

Adjust the rheostat, so that the deflection is 45° . Find the balancing length as before. Reverse the current in the tangent galvanometer and note the readings of the pointer. Find the average of the deflections.

Adjust the rheostat again, so that the deflection is 50° . Find the balancing length and the average deflection as before.

Operate the double-throw key and include the Daniel's cell in the secondary circuit of the potentiometer. Find the balancing length again. Take the mean of the two lengths.

Next, adjust the rheostat in the primary circuit, so that a small resistance from it is included in the circuit. Find the balancing lengths corresponding to (1) the Daniel's cell and (2) the standard resistance when the deflections in the tangent galvanometer are 40° , 45° , 50° .

Adjust the rheostat in the primary circuit again and take one more set of readings.

Note :—The resistance included in the primary circuit must be such that the balance point is obtained within the potentiometer for the Daniel's cell.

Calculations :— L is the balancing length corresponding to the E.M.F., E , of the Daniel's cell. L_1 is the length corresponding to the P.D. between the terminals of the standard resistance r . If the current in the standard resistance is C , this P.D. is $C \times r$.

$$\therefore \frac{E}{L} = \frac{C \times r}{L_1}$$

$$\therefore C = \frac{E \times L_1}{L \times r}$$

From the known values of E , r , L and L_1 , C can be calculated. Now,

$$C = K \tan \theta$$

where K is the reduction factor of the tangent galvanometer and θ , the average deflection.

$$\therefore K \tan \theta = \frac{E \times L_1}{L \times r}$$

$$\therefore K = \frac{E \times L_1}{L \times r \times \tan \theta}$$

Tabulate the results as follows :—

E. M. F. of Daniel's cell = E volts.

Standard Resistance = r ohms.

Balancing length with Daniel's cell	Balancing length with standard Resistance	Current	Deflection in Tangent galvanometer				Mean θ	tan θ .	$K = \frac{E \times L_1}{r \times L \times \tan \theta}$
			Direct		Reversed				
			θ_1	θ_2	θ_3	θ_4			
L	L_1	C							
cms.	cms.	amps.							
Mean									

$\therefore$ Mean value of the Reduction factor R =

(B) Calibration of ammeter

Apparatus required :—Potentiometer, two accumulators, a freshly prepared Daniel's cell, a standard one ohm resistance, an ammeter, a sensitive galvanometer, high resistance, two plug keys, double-throw key, two rheostats.

Procedure :—The circuit is the same as for the previous experiment, except that the tangent galvanometer and commutator are replaced by the ammeter to be calibrated.

Note :—The maximum P.D. that can be balanced on the potentiometer wire with one accumulator in the primary circuit is less than 2 volts. So, the current

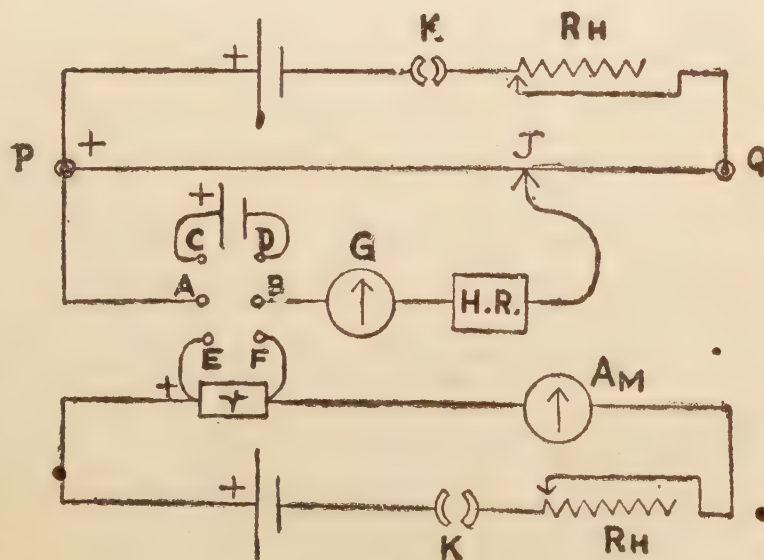


Fig. 190

range in the ammeter that can be calibrated depends on the standard resistance. If it is 1 ohm, the range is about 2 amperes. If it is half an ohm, it is about 4 amperes. Care must also be taken, to see that the maximum current passed through the standard resistance is well below the safe range..

First, close the primary circuit and find the balancing length L corresponding to the Daniel's cell, accurately.

Then, close the circuit containing the standard resistance and ammeter. Adjust the rheostat so that the ammeter reads, say, 0.2 ampere. With the double-throw key, include the standard resistance in the secondary circuit of the potentiometer. Find accurately the balancing length L_1 corresponding to the P.D. between the terminals of the standard resistance.

Adjust the rheostat, so that the ammeter reads 0.4, 0.6, 0.8, 1.0, etc., and find the balancing lengths corresponding to the P.D.s between the terminals of the standard resistance, when the respective currents passing through it cover the specified range in the ammeter.

Adjust the rheostat, so that the current passing through the circuit is decreased, and the ammeter readings are the same as before. Find the balancing lengths corresponding to each current.

Again, find the balancing length corresponding to the Daniel's cell. Take the mean of this and the previous length.

Calculations :—If L_1 is the balancing length corresponding to a current of C amps. passing through the standard resistance r ,

$$\frac{C \times r}{L_1} = \frac{E}{L}$$
$$\therefore C = \frac{E \times L_1}{r \times L}$$

Where E is the E.M.F. of the Daniel's cell and L is the balancing length for it.

From the known values of E , L_1 , r and L , calculate C .

Tabulate the results as follows :—

E.M.F. of Daniel's cell	=	E volts.
Standard Resistance	=	r ohms.

Amme- ter reading	Balancing length				Current Calculated $C = \frac{E \times L_1}{r \times L}$ amps	Difference between ammeter reading and calculated current
	For Daniel's cell L	For standard resistance				
		Current increasing	Current decreasing	Mean L ₁		

(C) Reduction factor of tangent galvanometer—
alternative method

Apparatus required :—Potentiometer, accumulator, freshly prepared Daniel's cell, tangent galvanometer, commutator, rheostat, resistance box, sensitive galvanometer, high resistance, plug key.

Procedure :—Connect the accumulator, the tangent galvanometer (through a commutator), a rheostat, a plug key and a resistance box R in series with the potentiometer wire PQ , to form the primary circuit, as shown in the diagram.

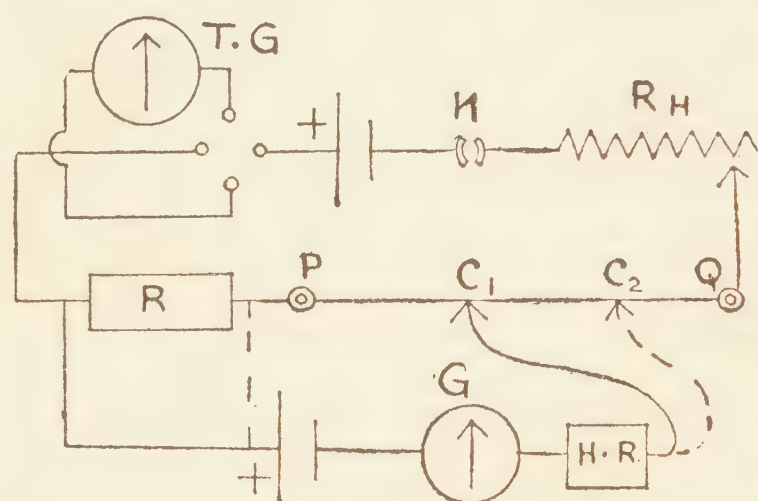


Fig. 191

Connect the positive terminal of the Daniel's cell to the positive end of the resistance box. Connect the negative terminal of the cell, in series with the sensitive galvanometer, a high resistance and the jockey, to form the secondary circuit.

Use the 50 turn coil of the galvanometer. Rotate the coil, so that it is in the magnetic meridian. Keep the rheostat at a distance from it. Unplug a resistance of, say, 10 ohms in the resistance Box R . Close the primary circuit. Adjust the rheostat, so that the deflection in the tangent galvanometer is about 45° .

Find the balance point C_1 with the jockey, first approximately. Cut out the high resistance and find it accurately. Measure the balancing length l_1 from the positive end P of the potentiometer wire.

Then, connect the positive terminal of the Daniel's cell to the negative end of the resistance box i.e., the positive end of the potentiometer wire. Find the balance point C_2 , as before, first approximately and then accurately. Measure the balancing length l_2 from the positive end P of the wire.

Note the deflection at both ends of the pointer of the tangent galvanometer. Reverse the current and note the deflections. Find the mean of the readings. Let it be θ .

It is obvious that the resistance of $(l_2 - l_1)$ cms. of the potentiometer wire is equal to 10 ohms,

$$\therefore \left. \begin{array}{l} \text{Resistance of 1 cm. of the} \\ \text{wire} \end{array} \right\} = \frac{10}{(l_2 - l_1)} \text{ ohms.}$$
$$= r \text{ ohms.}$$

The E.M.F. of the Daniel's cell, 1.08 volts, is balanced by l_2 cms. of the potentiometer wire.

$$\therefore \left. \begin{array}{l} \text{Fall of potential per cm.} \\ \text{length of wire} \end{array} \right\} = \frac{1.08}{l_2} \text{ volts.}$$

$\therefore$ Current C in the potentiometer wire

$$= \frac{\frac{1.08}{l_2}}{r} = \frac{1.08}{l_2 \times r}$$

If the mean deflection in the tangent galvanometer is θ ,

$C = K \tan \theta.$

$\therefore \frac{1.08}{r \times l_2} = K \tan \theta$

$\therefore K = \frac{1.08}{r \times l_2 \times \tan \theta}$

From the known values of r , l_2 and $\tan \theta$, the reduction factor K is calculated.

Change the resistance in the resistance box and repeat the experiment.

Tabulate the results as follows :—

Resistance in box R		Balancing length with		Resistance of 1 cm. of wire $r = \frac{R}{l_2 - l_1}$	Fall of Potential per cm. $\frac{1.08}{l_2}$	Deflection in Tangent Galvanometer				Mean θ	$\tan \theta$	$K = \frac{1.08}{r \times l_2 \times \tan \theta}$
Resistance inside l_1	Resistance outside l_2	Direct θ_1 θ_2	Reversed θ_3 θ_4									

$\therefore$ Mean value of the reduction factor K =

EXPERIMENT 87

RAYLEIGH'S POTENTIOMETER

Aim :—To compare the E.M.F. s of cells using Rayleigh's potentiometer.

Apparatus required :—Two resistance boxes of range 1 to 5000 ohms, accumulator, Daniel's cell, Lechlanche's cell, sensitive galvanometer, high resistance, plug key, double-pole double-throw key.

Procedure :—The accumulator is connected in series with the two resistance boxes and a plug key. Unplug a total resistance of 10000 ohms from the two boxes.

Let the two resistances be P and Q. Connect the terminal in P which is at the higher potential, to one of the common terminals A in the double-throw key.

Connect the other common terminal B in series with the sensitive galvanometer, the high resistance and the other terminal of P.

Connect the Daniel's cell to one pair of terminals C, D, and the Lechlanche's cell to the other pair of terminals E, F, in the double-throw key. See that the positive terminals of the Daniel's and the Lechlanche's cell are connected correctly.

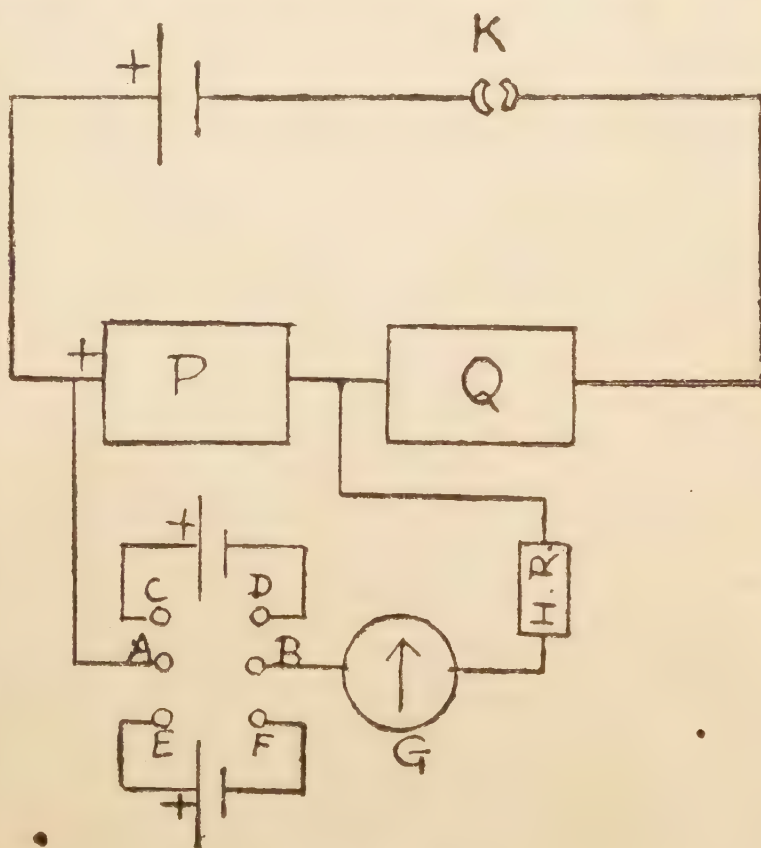


Fig. 192

Close the primary circuit. With the Daniel's cell in the secondary circuit, adjust the resistances in P and Q, so that the galvanometer shows nil deflection. Cut out the high resistance from the galvanometer circuit and determine the two resistances accurately. The sum of the resistances in the two boxes must be maintained constant at 10000 ohms. Note the resistances unplugged in P.

EXPERIMENT 88

POTENTIOMETER

CALIBRATION OF VOLTMETER

Aim :—To calibrate (1) a low range voltmeter and (2) a high range voltmeter, using the Potentiometer.

(A) Low range voltmeter

Apparatus required :—Two-metre or four-metre wire potentiometer, two accumulators, rheostat, resistance box, freshly prepared Daniel's cell, low range voltmeter, sensitive galvanometer, high resistance, plug keys.

Procedure :—A two-metre or four-metre wire potentiometer is best used for this experiment. Connect the two accumulators in series with a resistance box, a rheostat, a plug key and the potentiometer wire.

Connect the positive terminal of a freshly prepared Daniel's cell to the positive end P of the potentiometer wire. Connect the negative terminal of the Daniel's cell in series with a plug key, the sensitive galvanometer, high resistance and the jockey.

If the Daniel's cell is fresh, its E.M.F. may be assumed to be equal to 1.08 volts.

Have zero resistances in the rheostat and the resistance box in the primary circuit. Close the circuit. Close the

secondary circuit. Unplug the high resistance. Place the contact maker at 108 cms. Press it. Adjust the rheostat and, if necessary, unplug some resistances in the resistance box also, till the galvanometer shows no deflection. Cut out the high resistance, adjust the rheostat again till the deflection is zero.

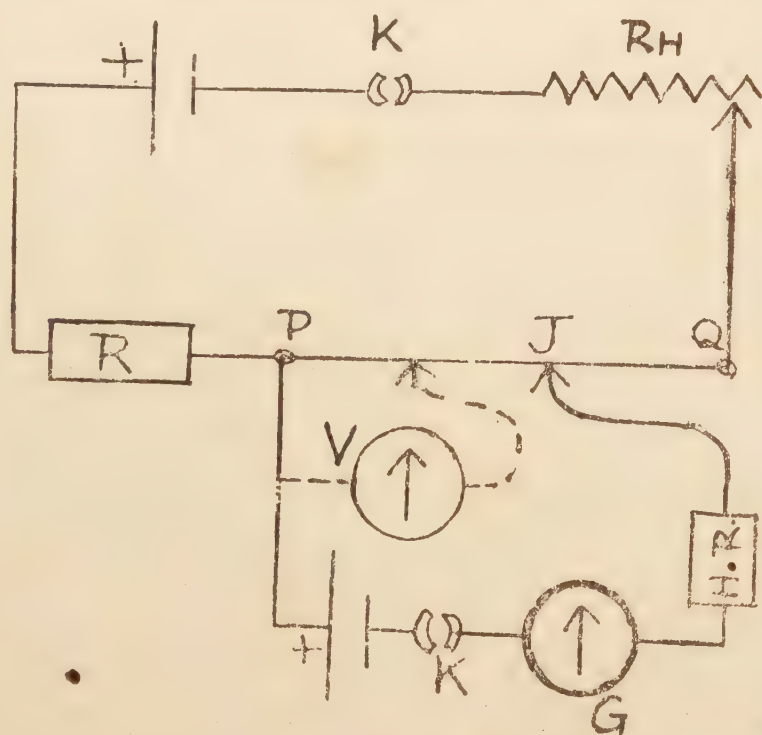


Fig. 193

The E.M.F. of the Daniel's cell is balanced by the P.D. between the positive end P of the potentiometer wire and the balance point. This length is 108 cms. The E.M.F. is 1.08 volts. So, the fall of potential per cm. is 0.01 volt.

Cut out the circuit of the Daniel's cell. Connect the positive terminal of the voltmeter to the positive end P of the potentiometer wire. Connect the other terminal of the voltmeter to the jockey. Move the jockey and find accurately the balancing point corresponding to, say, 0.2 volt reading in the voltmeter. Measure the distance of the balance point from the positive end. The length multiplied by the fall of potential per cm. gives the P.D. corresponding to the length. The difference between the calculated P.D. and voltmeter reading is the correction.

Find, likewise, the balancing lengths corresponding to the voltmeter readings 0.4, 0.6, 0.8, 1.0, 1.2 etc., volts. Calculate the corrections for each of the readings.

The above method is applicable upto a range of 2 to 4 volts.

Tabulate the results as follows :—

E.M.F. of Daniel's cell	=	1.08 volts.
Balancing length on potentiometer wire	=	108 cms.
∴ Fall of potential per cm.	=	0.01 volt.

Voltmeter reading volts	Corresponding balancing length cms.	P.D. calculated. volts	Correction for voltmeter reading
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(B) High range voltmeter

Apparatus required :—Two-metre or four-metre wire potentiometer, two accumulators, high range voltmeter, battery of E.M.F. higher than the maximum indicated by voltmeter, large resistance rheostat, a low value standard resistance, a resistance box, sensitive galvanometer, high resistance, rheostat, double-throw key, plug keys.

Procedure :—Connect up the circuit as shown in the diagram.

B is a battery which has an E.M.F. larger than the maximum indicated by the voltmeter. X Y is a rheostat having a large resistance and the suitable current carrying capacity. Connect the battery B, the rheostat X Y and a plug key in series. Use the fixed terminals at the two ends of the rheostat and include the whole of the resistance in the circuit.

Connect the voltmeter terminals to one of the fixed terminals X in the rheostat and the sliding contact Z. By altering the position of the sliding contact Z, the voltmeter readings can be adjusted for any value.

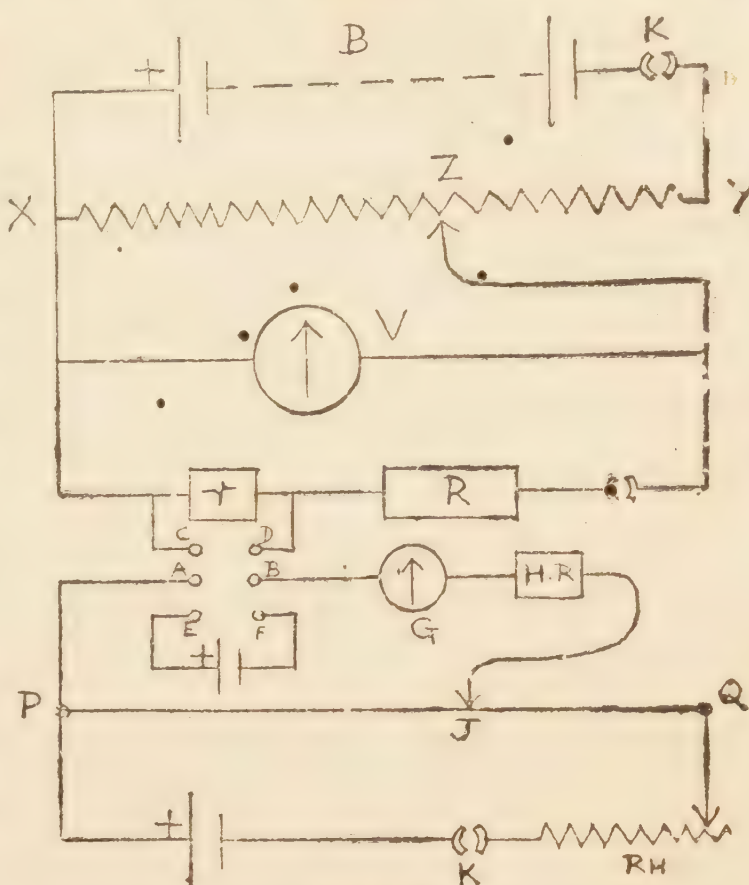


Fig. 194

Connect in parallel with the voltmeter, the low value standard resistance r and a resistance box R . A resistance which is an exact multiple of r , say $n \times r$, is unplugged from R .

The terminals of r are connected to one pair of terminals in the double-throw key.

One of the common terminals in the double-throw key is connected to the positive end P of the two or four—metre long potentiometer wire. The other terminal is connected through the sensitive galvanometer and the high resistance to the jockey.

To the other pair of terminals of the double-throw key a Daniel's cell is connected.

The primary circuit of the potentiometer consists of one or two accumulators, a plug-key and rheostat.

Using the Daniel's cell, standardise the potentiometer circuit, for a fall of potential of 0.01 volt per cm.

Manipulate the double-throw key and include the standard resistance r in the secondary circuit.

Adjust the position of Z, so that the reading of the voltmeter is a definite fraction of the range of the voltmeter. Thus, if the range is 0—100 volts, and if the calibration is to be done in 20 steps, the first reading will be 5 volts.

Find the balance point in the potentiometer wire, corresponding to the P.D. between the terminals of r . Calculate the P.D. If it is v , $\frac{v \times (n + 1)r}{r}$ or $v(n + 1)$ must be the correct voltmeter reading. The difference between this and the actual reading will be the correction.

Find the balance points corresponding to the readings of 10, 15, 20, etc. volts in the voltmeter. Calculate the P.Ds. in each case and find the corrections to the readings.

Tabulate the results as follows :—

E. M. F. of Daniel's cell	=	1.08 volts
Balancing length in potentiometer	=	108 cms.
$\therefore$ Fall of potential per cm	=	0.01 volts

Voltmeter reading volts	Balancing length on potentiometer l cms.	P. D. between terminals of r . v volts	P.D. between the terminals of $(r + R)$. $(n + 1)v$ volts	Correction for voltmeter reading volts.
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EXPERIMENT 89

POTENTIOMETER

E. M. F. OF THERMO-COMPLE

Aim :—To determine the E.M.F. of a Thermo-couple, using the potentiometer.

Apparatus required :—Potentiometer, accumulator, freshly prepared Daniel's cell, two resistance boxes, thermo-couple (copper-iron or copper-constantan), sensitive galvanometer, high resistance, plug key.

Procedure :—The potentiometer is first calibrated for a fall of potential of 1 milli-volt per metre length of it and the E.M.F. of the thermo-couple measured. This is done in three stages.

(1) Resistance of potentiometer wire

Connect the accumulator, a plug key, two resistance boxes R_1 , R_2 and the potentiometer wire in series, to form the primary circuit, as shown in the diagram.

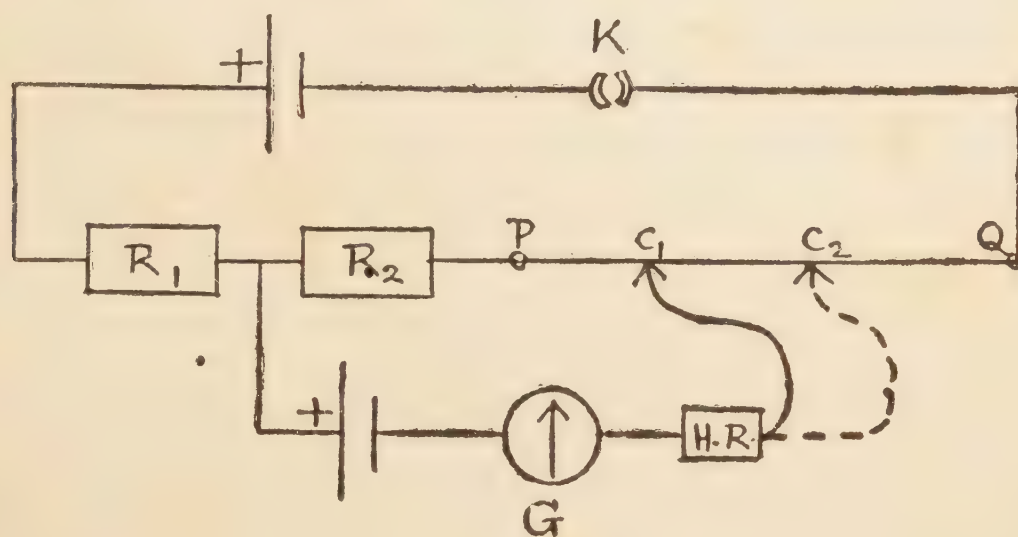


Fig. 195

Connect the positive terminal of the Daniel's cell to the junction between R_1 and R_2 . Connect its negative terminal through the sensitive galvanometer and the high resistance to the jockey.

Unplug, say, 5 ohms from the resistance box R_2 . Have zero resistance in R_1 . Close the primary circuit. Find the balance point C_1 , first approximately and then accurately, after cutting out the high resistance. Measure the balancing length l_1 from the positive end P of the wire.

Transfer the 5 ohms from box R_2 to R_1 . There will be zero resistance in box R_2 . Find the balance point C_2 as before. Measure the balancing length l_2 from the positive end P of the wire.

Obviously, the resistance of $(l_2 - l_1)$ cms. of wire is 5 ohms. So, the resistance per cm. length of wire is $\frac{5}{(l_2 - l_1)}$ ohms. Hence, the resistance r of the whole wire is $\frac{5}{(l_2 - l_1)} \times 1000$ ohms.

Unplug 10 ohms from R_2 and find the balancing length. Transfer it to R_1 and find the balancing length. Calculate the resistance per cm. length of wire.

Repeat for a resistance of 15 ohms.

Tabulate the result as follows :—

Resistance unplugged R ohms	Balancing length with		Resistance of potentiometer wire $r = \frac{R \times 1000}{(l_2 - l_1)} \text{ ohms.}$
	Resistance inside l_1 cms.	Resistance outside l_2 cms.	

(2) Calibration of potentiometer wire

The E.M.F. of a thermo-couple, copper-iron or copper-constantan, is of the order of a few milli-volts, when the difference in temperature between the hot and cold junctions is about 100°C . So, calibrate the potentiometer for a fall of potential wire of 1 milli-volt per metre. Calculate as follows:—

Required fall of potential per metre = 1 milli-volt

$\therefore$ P.D. between terminals of potentiometer wire } = 10 milli-volts

Resistance of the potentiometer wire = r ohms.

For a P.D. of 10 milli-volts, resistance in circuit is r ohms.

$\therefore$ For a P.D. of 1 milli-volt, resistance is $\frac{r}{10}$ ohms

The E.M.F. of Daniel's cell is 1.08 volts.

$\therefore$ For E.M.F. of 1.08 volts, resistance required

$$= \frac{r}{10} \times 1.08 \times 1000 = r \times 108 \text{ ohms.}$$

Hence, if the Daniel's cell is connected to a resistance of $r \times 108$ ohms, the P.D. corresponding to r ohms will be 10 milli-volts.

Connect up the primary and the secondary circuit as shown in the diagram.

Unplug $108 \times r$ ohms from resistance box R_2 . If this is a fraction, the fraction cannot be unplugged from the resistance

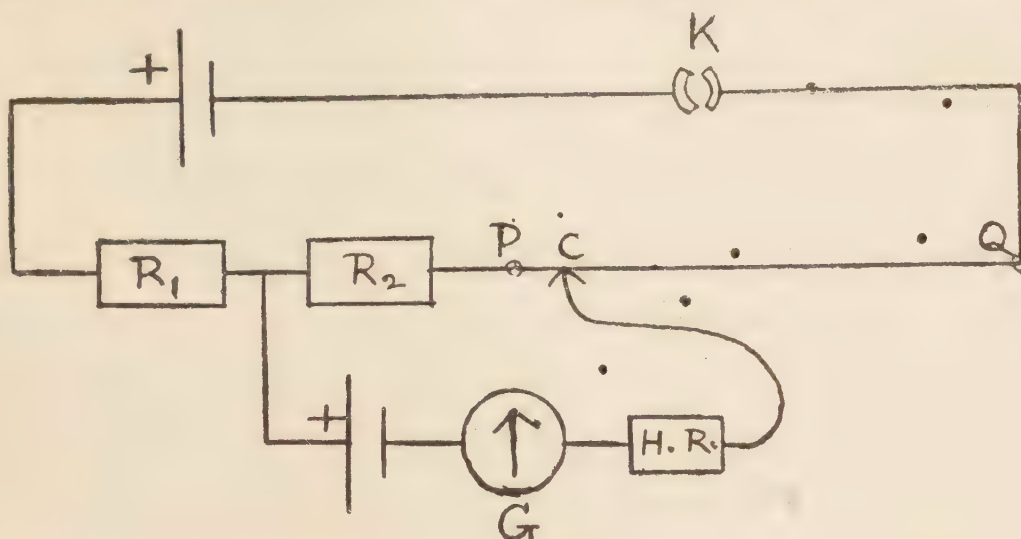


Fig. 196

box. So, for the fraction required, calculate the corresponding length of potentiometer wire and keep the contact maker at that point C.

Press the contact maker at C. Remove such a resistance from box R_1 , that the galvanometer shows no deflection, when the contact maker is pressed at C. Now, the P.D. between the terminals of R_2 and the small length PC of the potentiometer wire is balanced by the E.M.F. of the Daniel's cell. The fall of potential per metre length of the wire is 1 milli-volt.

E.M.F. of Thermo-couple :—Do not disturb the resistances in R_1 and R_2 .

Connect one of the terminals of the thermo-couple to the positive end P of the potentiometer wire. Connect the other

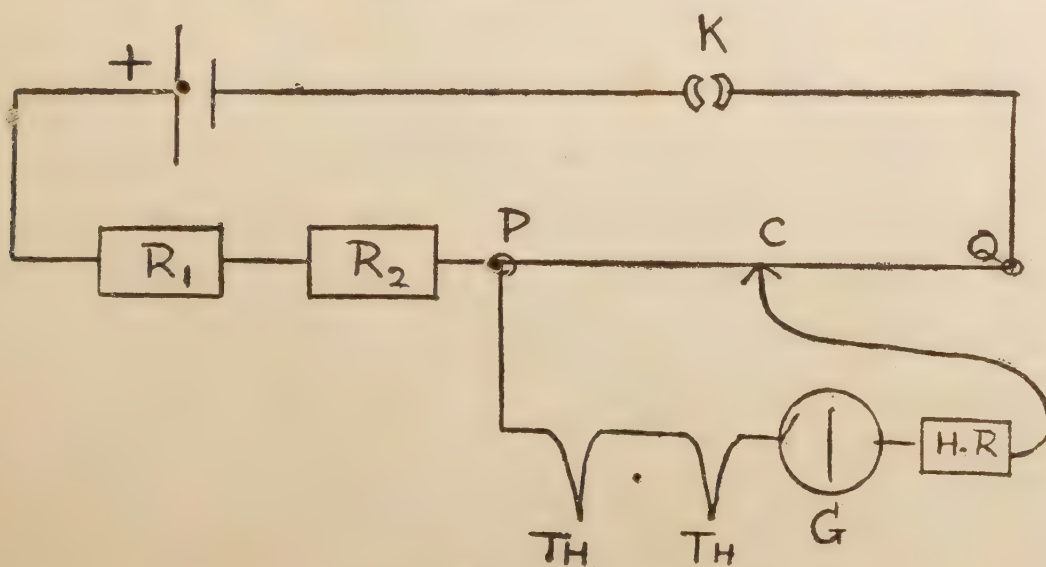


Fig. 197

terminal through the galvanometer and high resistance to the jockey.

One of the junctions is kept in a water bath maintained at a constant temperature, either 0°C or the room temperature.

The other junction is kept in a water bath, whose temperature is raised. When the difference in temperature between the two junctions is zero, there will be no thermo-E.M.F.

Heat one of the junctions to 45°C . Maintain the temperature of the hot junction constant for a few minutes. Find the balance point C. (If the deflection is in one direction only, it is due to the faulty connection of the thermo-couple junction. Reverse the connections.) Measure the balancing length PC, from the positive end P of the potentiometer wire.

Raise the temperature of the hot junction to 60°C , 75°C and the boiling point of water. Find the balancing lengths in each case.

Lower the temperature and measure the balancing lengths corresponding to the temperatures of 75° , 60° , and 45° of the hot junction.

Tabulate the results as follows :—

Temperature of		Balancing length when		P.D. between junctions	Thermo- E.M.F. per degree difference in temp.
Hot junction	Cold junction	Temperature is			
		rising	falling		

Note :—For the second and third part of the experiment, a more sensitive galvanometer than was used for experiments performed hitherto is required. Use a unipivot galvanometer or a mirror galvanometer. Otherwise it may not be possible to get the balance point *accurately*.

EXPERIMENT 90

MIRROR GALVANOMETER

RESISTANCE AND FIGURE OF MERIT.

Aim :—To determine the resistance of a mirror galvanometer by the half deflection method and to calculate its figure of merit—current and volt sensitivity.

Apparatus required :—Accumulator, two resistance boxes of range 1 to 5,000 ohms, one resistance box of range 1 to 100 ohms, a mirror galvanometer, commutator, plug key.

Description of apparatus :—The mirror galvanometer generally used is of the moving coil type. It consists of a coil of wire wound over a frame and suspended by a phosphor bronze wire between the poles of a powerful magnet of the horse-shoe type. The phosphor bronze wire also serves to carry the current to the coil. A spiral of phosphor bronze wire connected at the bottom of the coil serves to lead the current away from it. A soft iron sphere or cylinder (depending on the shape of the coil) mounted inside the coil makes more magnetic lines of force traverse the coil radially. The soft iron piece does not, however, impede the rotational movement of the coil. The galvanometer is *aperiodic*, if, due to damping, it comes to rest quickly, after a few oscillations. It is *ballistic*, if, due to little or no damping, it makes a large number of oscillations before coming to rest.

A plane or concave mirror about 1 cm. in diameter is fitted just above the coil. A spot of light directed at the mirror is reflected and received on a translucent scale. When the coil is deflected, the mirror also turns and the spot of light moves on the scale.

Procedure :—Connect in series, the accumulator, one of the resistance boxes P of range 1—5,000 ohms, the resistance box Q of the smaller range and the plug key.

Connect in parallel with the terminals of the smaller resistance Q, the other resistance box R of range 1—5,000

ohms and the mirror galvanometer through the commutator.

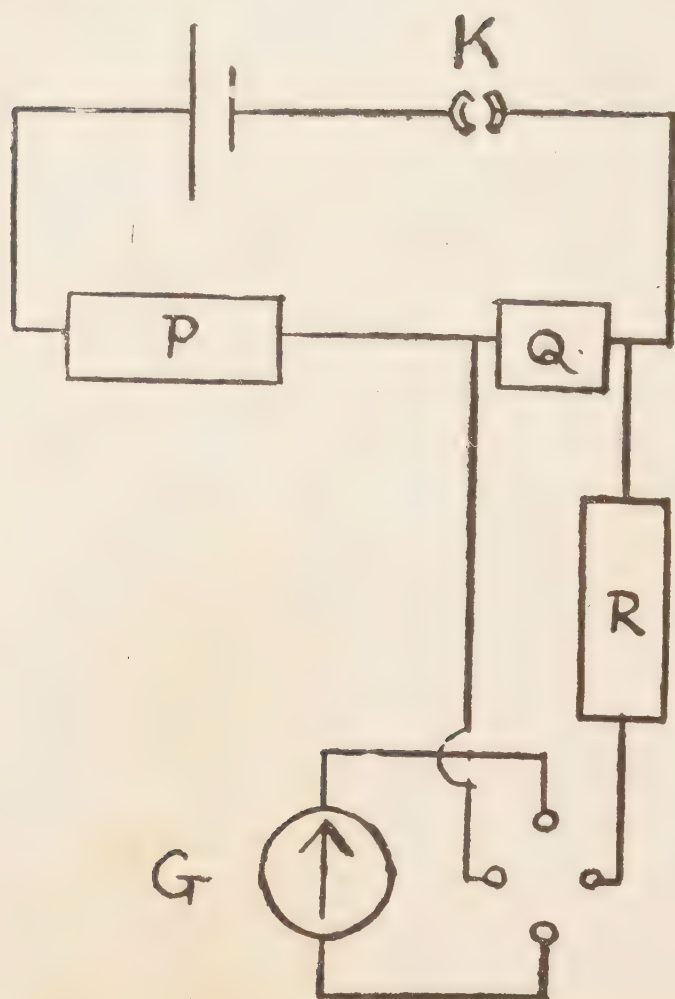


Fig. 198

Unplug 9,999 ohms from P and 1 ohm from Q. Have zero resistance R in the galvanometer circuit.

Switch on the galvanometer lamp. See if the spot of light falls on the mirror and is reflected on to the scale. Adjust the position of the scale, so that the spot of light is at the centre of the scale. Usually, the spot of light is a circle with a dark reference line at its centre. Make this line coincide with the centre of the scale.

Close the main circuit.

Note the deflection of the spot of light on the scale. Reverse the current in the galvanometer and note the deflection.

Unplug resistances from the box R, so that the deflection is reduced to half. Note the resistance required for reducing the deflection to half the value both on the right and on the left. The relation between the deflection and the current in the galvanometer circuit is linear. [This is true so long as the resistance Q is very small compared with the resistance of the galvanometer.] So the resistance unplugged is *equal* to the resistance R_g of the galvanometer.

Unplug 2 ohms from the box Q and have 9,998 ohms in box P, so that the total resistance is the same as before. Note the deflections on both sides. Find also the resistances to be unplugged from R to reduce the deflection to half the value on each side.

Repeat the experiment, unplugging 3, 4, 5, etc., ohms from the box Q, but always keeping the total resistance unplugged

EXPERIMENT 91

MIRROR GALVANOMETER

E.M.F. OF THERMO-COUPLE BY DIRECT DEFLECTION

Aim :—To determine the E.M.F. of a thermo-couple by direct deflection, using a mirror galvanometer.

Apparatus :—Mirror galvanometer, thermo-couple (copper-iron or copper-constantan), two resistance boxes of range 1 — 5,000 ohms, one resistance box of range 1 — 100 ohms, an accumulator, plug key, commutator.

Procedure :—Connect the ends of the thermo-couple to a resistance box R (1 — 5,000 ohms) and to the mirror galvanometer through a commutator.

Introduce one of the junctions of the thermocouple in a water-bath maintained at constant temperature 0°C or room temperature and the other in a water-bath which can be heated. Raise the temperature of this water-bath to that of the boiling point of water. Watch the deflection on the scale. Unplug resistances in the box, if necessary, and keep the deflection within the scale. At the maximum temperature, the deflection must be the maximum that could be read on the scale. Note the deflection. Reverse the current in the galvanometer and note the deflection. Note the temperatures of the hot and the cold junctions.

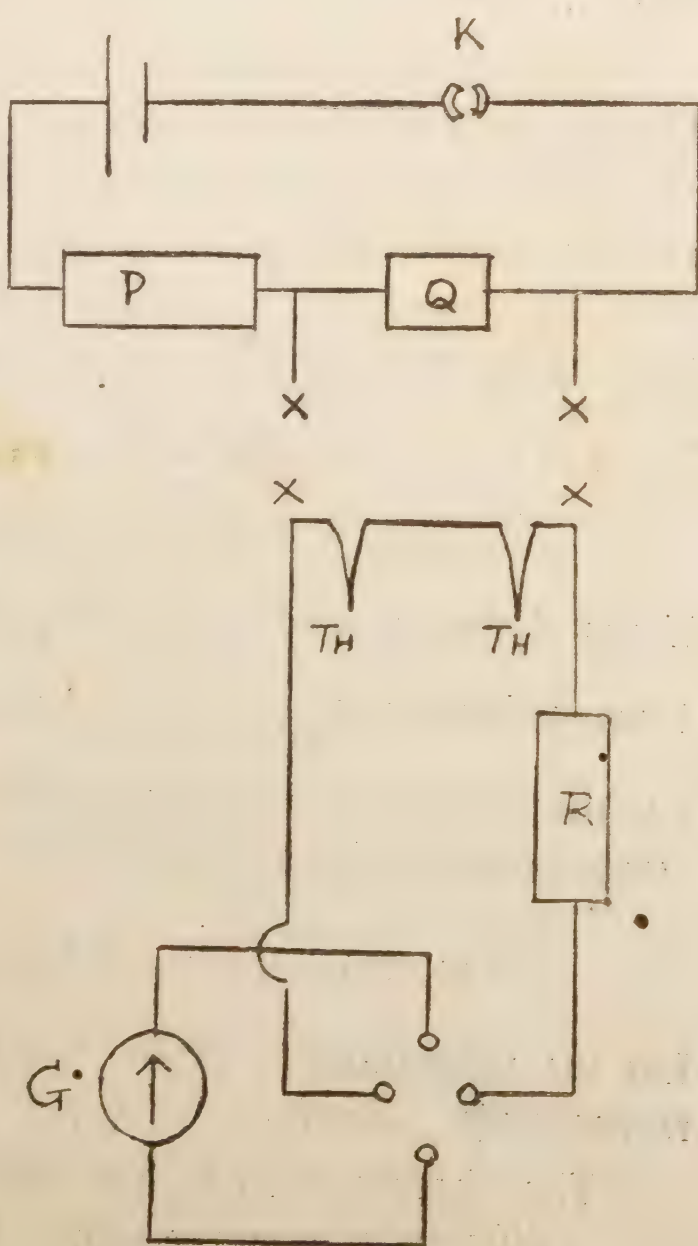


Fig. 199

Cool the hot junction to 75°C . Maintain the temperature constant for a few minutes. Note the deflection. Reverse the current and note the deflection.

Cool the hot junction to 60°C and 45°C . At each temperature, maintain it constant for a few minutes. Note the deflections on both sides of the centre.

Raise the hot junction to 60° , 75° and the boiling point of water. At each temperature, maintain it constant for a few minutes. Note the deflections on both sides of the centre.

Connect the accumulator, a resistance box P of range 1—5,000 ohms, a resistance box Q of range 1 — 100 ohms and the plug key in series.

Disconnect the wires from the ends of the thermo-couple and connect them to the terminals xx of the low range resistance box Q . Do not alter the resistance in box R .

Unplug 10,000 ohms in box P . Close the accumulator circuit. Unplug such small resistances in Q , of the order of 1 to 10 ohms, such that the deflection produced is of the same order as with the thermo-couple. Keep the total resistance in P and Q constant. Note the deflections corresponding to known resistances in Q . Reverse the current and note the deflections, in each case.

Let E be the E.M.F. of the accumulator.

The P.D. between the terminals of $Q = \frac{EQ}{(P + Q)}$ volts.

If the deflection produced is d_2 , the P.D. required to produce 1 cm. deflection is $\frac{EQ}{(P + Q) d_2}$ volts.

Let the deflection produced by the thermo-couple for a particular temperature of the hot junction be d_1 . Then,

The corresponding P.D. = $\frac{EQ \times d_1}{(P + Q) \times d_2}$ volts.

Let the temperatures of the hot and cold junctions be T_2 and T_1 respectively. Then,

The thermo-E.M.F. per degree }
difference in temperature } = $\frac{EQ \times d_1}{(P + Q) \times d_2 \times (T_2 - T_1)}$

Note.— R must be the same in both experiments.

Tabulate the results as follows :—

E.M.F. of accumulator = 2 volts

Temperature		Deflection on scale			Resistance		Deflection on scale			Thermo-E.M.F. per degree dif. of Temp. $E \times Q \times d_1$ $(P+Q) \times d_2 \times (T_2 - T_1)$
Hot junction	Cold junction	Left	Right	Mean d_1	Q	P	Left	Right	Mean d_2	
T_2	T_1									
Mean										

$$\therefore \left. \begin{array}{l} \text{Mean thermo—E.M.F. per degree} \\ \text{difference of temperature between} \\ \text{the hot and cold junction} \end{array} \right\} =$$

EXPERIMENT 92

MIRROR GALVANOMETER

COMPARISON OF RESISTANCES

Aim :—To compare (1) low resistances and (2) high resistances by direct deflection, using a mirror galvanometer.

(A) Comparision of Low Resistances

Apparatus required :—Mirror galvanometer, resistance box of range 1 to 5,000 ohms, accumulator, resistances to be compared, double-throw key, commutator.

Procedure :—Connect up an accumulator, the resistance box P, the two low resistances R and X of the same order, and the plug key in series, as shown in the diagram.

Connect the common terminals of the double-throw key to the mirror galvanometer, through a commutator.

Connect the ends of one of the low resistances

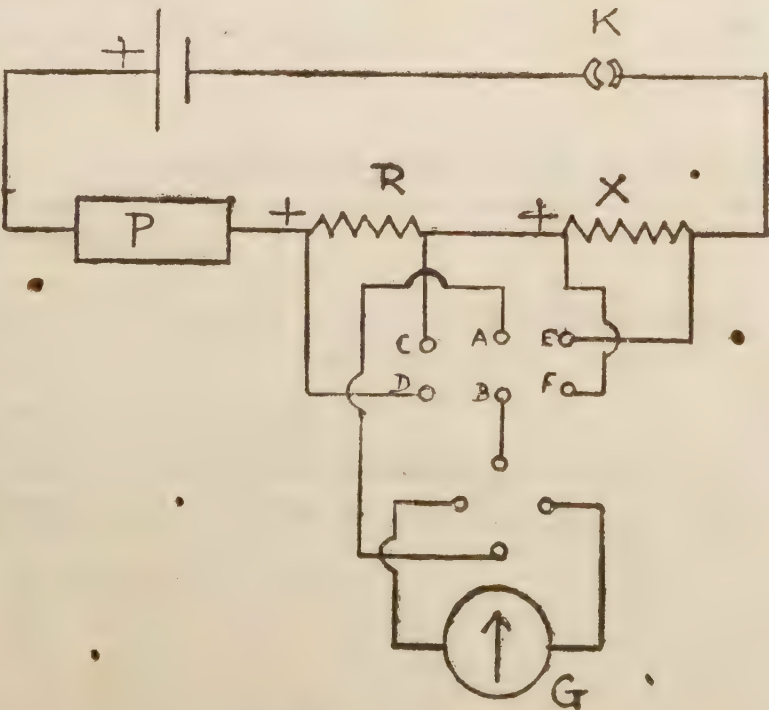


Fig. 200

R to one pair of terminals C, D in the double-throw key and the ends of the other resistance X to the other pair of terminals E, F in the key.

Unplug a large resistance of, say, 10,000 ohms in the resistance box P. Close the circuit.

Apply the P.D. between the terminals of one of the low resistances, R to the mirror galvanometer. Note the deflection. Reverse the current in the galvanometer and note the deflection. Find the mean of the two. Let it be d_1 .

With the double-throw key, apply the P.D. between the terminals of the other resistance X to the galvanometer. Note the deflection. Reverse the current in the galvanometer and note the deflection. Find the mean of the two. Let it be d_2 .

Since the same current is passing through both the resistances, the P.D.s between their ends are proportional to their resistances. The deflection in the galvanometer is proportional to the P.D. applied to it. Hence, the ratio of the resistances $\frac{R}{X}$ is equal to the ratio of the deflections $\frac{d_1}{d_2}$. If one of the resistances is known, the other can be calculated.

Alter the resistance in P. Note the mean deflections in the galvanometer corresponding to the P.D.s between the terminals of R and X. Repeat the experiment and take half a dozen readings.

Note.—The resistance unplugged from P must be such that a fairly large deflection is produced in the galvanometer. It depends on the sensitivity of the galvanometer and the resistances R and X.

Tabulate the readings as follows :—

Resistance P	R ohms.	X ohms.	Deflection in galvanometer						$\frac{X}{R}$	$\frac{d_1}{d_2}$
			due to P.D. in R			due to P.D. in X				
			Left	Right	Mean	Left	Right	Mean		

If X is not known, it can be calculated.

$$\frac{R}{X} = \frac{d_1}{d_2}$$
$$\therefore X = \frac{R \times d_2}{d_1} \text{ ohms.}$$

(B) Comparison of High Resistances

Apparatus required :—Mirror galvanometer, accumulator, two high resistances of the same order, a resistance box of range 1 to 100 ohms, plug key, commutator, double-throw key.

Procedure :—Connect the accumulator, the two common terminals of the double-throw key and the plug key, in series with the mirror galvanometer through the commutator, as shown in the diagram. Connect the resistance box S in parallel with the galvanometer. Connect the ends of one of the high resistances to one pair of terminals in the double-throw key and the ends of the other high resistance to the other pair of terminals.

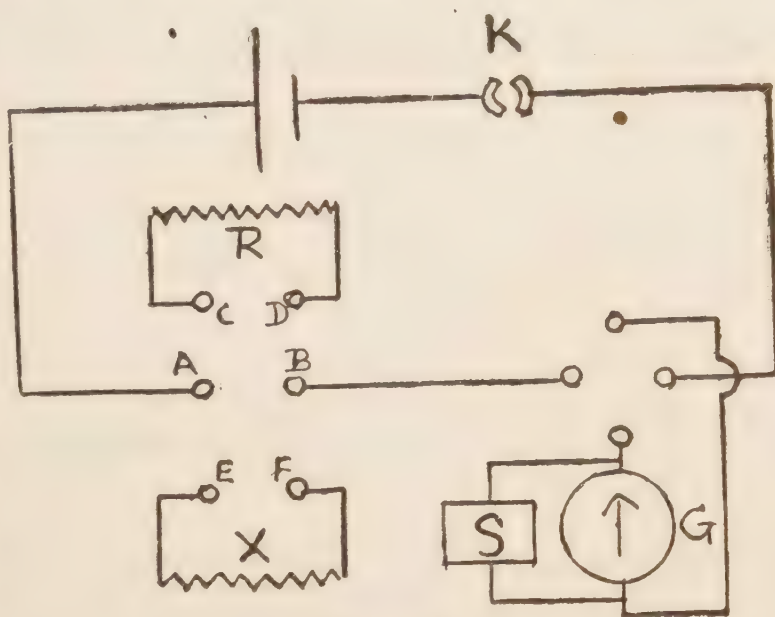


Fig. 201

Note.—The high resistances must be of such a value that, when any one of them is connected in series with the galvanometer and the accumulator, a good deflection is produced on the scale. If the resistances are very high, of the order of a few megohms a sensitive galvanometer must be chosen. If the resistances are not very high, the galvanometer must be protected by a suitable low resistance shunt. The resistance box S connected in parallel with the galvanometer will serve the purpose.

Unplug a resistance of, say, 1 ohm in the resistance box S . Insert the plug key K .

Close the circuit with resistance R included in it. Note the deflection in the galvanometer. Adjust the value of the resistance in box S , such that the deflection is large. If the deflection is small, increase the resistance unplugged in box S , till a large deflection is obtained. If it is still small, the box S may be cut out.

Note the deflection. Reverse the current in the galvanometer and note the deflection. Find the mean of the two. Let it be d_1 .

Using the double-throw key, include X in the circuit and note the deflection in the galvanometer. Reverse the current and note the deflection. Find the mean of the two. Let it be d_2 .

Let E be the E.M.F. of the cell. If the resistances are so large, that the galvanometer resistance (with shunt) is negligible,

$$\text{current with } R \text{ in circuit} = \frac{E}{R}$$

$$\text{and current with } X \text{ in circuit} = \frac{E}{X}$$

$$\therefore \text{Ratio of the currents} = \frac{\frac{E}{R}}{\frac{E}{X}} = \frac{X}{R}$$

$$\therefore \frac{X}{R} = \frac{d_1}{d_2}.$$

If R , d_1 and d_2 are known, X can be calculated.

By adjusting the value of the resistance in box S , a number of readings can be taken.

Tabulate the readings as follows :—

Resistance in box S ohms	R ohms	X ohms	Deflection in galvanometer						$\frac{X}{R}$	$\frac{d_1}{d_2}$
			R in circuit			X in circuit				
			Left	Right	Mean d_1	Left	Right	Mean d_2		

$$\frac{X}{R} = \frac{d_1}{d_2}$$

If X is unknown, it can be calculated.

$$\therefore X = \frac{R \times d_1}{d_2} \text{ ohms.}$$

EXPERIMENT 93

BALLISTIC GALVANOMETER

COMPARISON OF CAPACITIES AND E.M.F.s

Aim :—To compare (1) the capacities of two condensers and (2) the E.M.F.s of two cells, using a ballistic galvanometer.

(A) Comparison of Capacities.

Apparatus required :—Two condensers of different capacities, accumulator, two resistance boxes of range 1 to 5,000 ohms, ballistic galvanometer, charge and discharge key, double-throw key, plug key, commutator.

Procedure :—Connect the accumulator in series with the two resistance boxes P and Q of range 1 to 5,000 ohms, through the plug key K.

Connect the ends of one of the boxes Q to the common terminals A, B of the double-throw key, through the common terminal X and one of the other terminals Y of the charge and discharge key.

Connect the ends of one of the condensers C_1 to one pair of terminals C, D of the double-throw key and the ends of the other condenser C_2 to the other pair of terminals E, F.

Connect the ends of the galvanometer through the commutator to the common terminals A, B of the double-throw key through the terminal Z of the charge and discharge key.

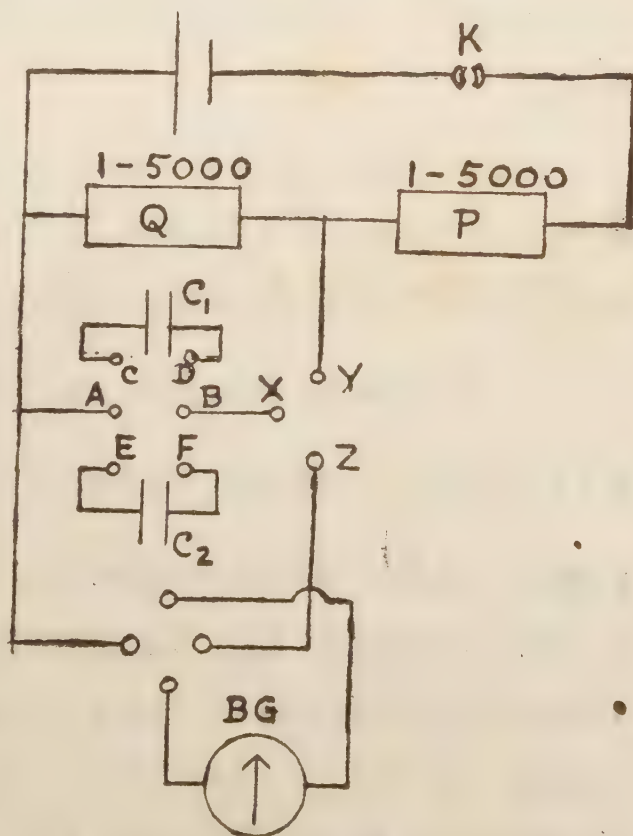


Fig. 202

Refer to the circuit diagram and check up the connections.

Unplug 5,000 ohms in Q and 5,000 ohms in P. Close the main circuit.

With the double-throw key, include the condenser C_1 in the circuit of the accumulator. Establish contact between the terminals X and Y in the charge and discharge key. The condenser will be charged by the P.D. between the terminals of the resistance box Q. Connect X and Z. The condenser will be discharged through the galvanometer. Note the deflection or throw on the scale.

Reverse the commutator. Charge the condenser C_1 again and discharge it through the galvanometer. The throw will now be on the opposite side. Note the deflection. Let the mean deflection be d_1 .

Using the double-throw key, connect C_2 to the circuit of the accumulator. Without altering the resistances in P and Q, charge C_2 and discharge it through the galvanometer with the charge and discharge key. Note the throw.

Reverse the commutator. Charge the condenser again and discharge it. Note the throw. Let the mean of the two throws be d_2 .

Alter the resistance in Q and repeat the experiment. For the same resistances in Q and P, note the throws produced by charging and discharging the condensers.

If P and Q are the resistances unplugged in the boxes, the P.D. between the terminals of Q is $\frac{EQ}{P+Q}$, where E is the E.M.F. of the accumulator. Let P.D. this be V. When it is applied to the conductor C_1 , the quantity of electricity stored in it is VC_1 . When it is applied to the conductor C_2 , the quantity of electricity stored is VC_2 . Let the respective deflections produced by discharging them through the galvanometer be d_1 and d_2 . The deflection is proportional to the quantity of electricity passing through the galvanometer. Hence,

$$\frac{VC_1}{VC_2} = \frac{d_1}{d_2} \quad \therefore \quad \frac{C_1}{C_2} = \frac{d_1}{d_2}$$

Tabulate the results as follows :—

Resis- tance P + Q	Resis- tance Q	Throw due to C ₁			Throw due to C ₂			$\frac{d_1}{d_2}$
		Left	Right	Mean d ₁	Left	Right	Mean d ₂	
ohms	ohms							
							Mean ...	

$$\therefore \text{Mean } \frac{C_1}{C_2} =$$

(B) Comparison of E.M.F.s of cells.

Apparatus required.—Two or three cells of different E.M.F.s, a condenser, two resistance boxes of range 1 to 5,000 ohms, double-throw key, charge and discharge key, ballistic galvanometer, commutator, plug key.

Procedure :—Connect the two resistance boxes P and Q, the common terminals A, B of the double-throw key and the plug key K in series.

Connect one of the cells E₁ to one pair of terminals C, D in the double-throw key and the other cell E₂ to the other pair of terminals E, F.

Connect the ends of the resistance box Q to the ends of the condenser through the common terminal X and one of the other terminals Y of the charge and discharge key.

Connect the ballistic galvanometer through the

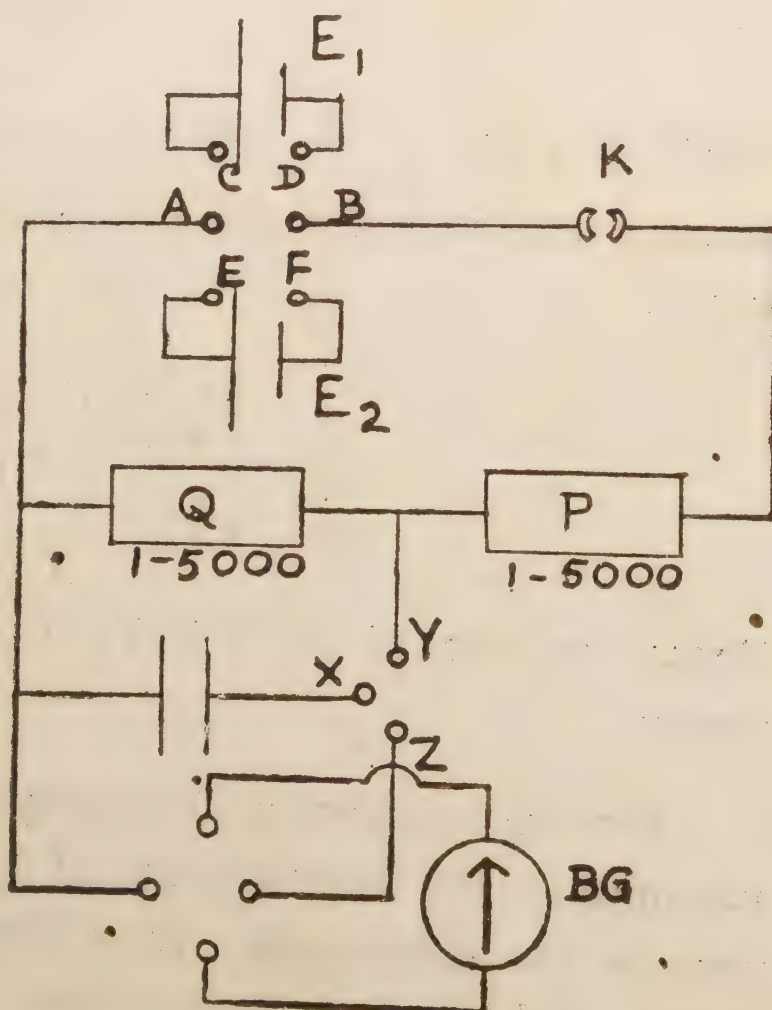


Fig. 203

commutator to the end of the condenser through the other terminal Z of the charge and discharge key.

Check up the connections with the circuit diagram.

Unplug 5,000 ohms in Q and 5,000 ohms in P.

With the double-throw key, include cell E_1 in the circuit of the resistances. Close the circuit.

Connect X and Y in the charge and discharge key. The condenser will be charged. Discharge it through the galvanometer and note the throw. Reverse the commutator. Charge the condenser and discharge it. Note the throw, which will now be on the opposite side. Let the mean of the two be d_1 .

With the double-throw key, change over to the other cell E_2 . Charge the condenser and discharge it. Note the throw. Reverse the commutator. Charge the condenser again and discharge it. Note the throw. Let the mean of the two be d_2 .

Then, with cell E_1 in circuit, the condenser is charged by P.D. equal to $\frac{E_1 Q}{P+Q}$. With E_2 in the circuit, it is charged by P.D. equal to $\frac{E_2 Q}{P+Q}$. The respective throws, when the condenser is charged and discharged, are proportional to the quantities of electricity. So,

$$\frac{d_1}{d_2} = \frac{\frac{E_1 Q}{P+Q} \times C}{\frac{E_2 Q}{P+Q} \times C} = \frac{E_1}{E_2}.$$

Hence, the ratio of the E.M.Fs. is equal to the ratio of the throws.

Alter the resistance in Q keeping $(P+Q)$ constant. Repeat the experiment. For the same value of Q and $(P+Q)$, find the deflections in the galvanometer corresponding to E_1 and E_2 in the circuit. Take three or four readings.

Tabulate the readings as follows :—

[illegible]

$$\therefore \text{Mean } \frac{E_1}{E_2} =$$

EXPERIMENT 94

BALLISTIC GALVANOMETER

ABSOLUTE CAPACITY OF A CONDENSER

Aim :—To determine the absolute capacity of a condenser, using a ballistic galvanometer.

Apparatus required :—Ballistic galvanometer, accumulator, two resistance boxes of range 1 to 5,000 ohms, one resistance box of range 1 to 100 ohms, condenser, charge and discharge key, plug key, stop-watch.

Procedure :—Connect the accumulator of steady E.M.F. in series with the two resistance boxes P and Q of range 1 to 5,000 ohms and a plug key K, as in the diagram.

Connect the ends of the resistance box P to the condenser through the charge and discharge key, using the common terminal X in it and one of the other terminals Y . When X and Y are in contact, the condenser will be charged by the P. D. between the ends of the resistance box.

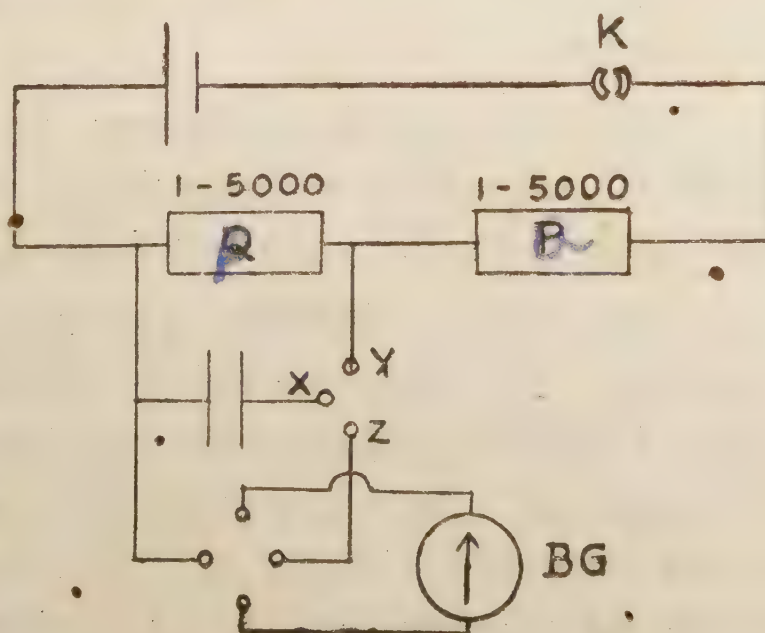


Fig. 204

Connect the ballistic galvanometer through the commutator in parallel with the condenser, using the third terminal Z in the key. If the condenser is charged when X and Y are in contact, it will be discharged through the galvanometer when X and Z are in contact.

Unplug 5000 ohms in Q and 5000 ohms in P. Close the main circuit.

Establish contact between X and Y in the key and charge the condenser. Discharge it through the galvanometer by connecting X and Z. Note the throw of the spot of light on the scale.

Note :—The throw depends on (1) the P.D. between the terminals of Q, (2) the capacity of the condenser and (3) the sensitivity of the galvanometer. So, for a given condenser, with a given galvanometer, adjust the values of Q and P, and get a good throw.

Note the throw produced. Reverse the commutator. Charge the condenser again and discharge it. The throw will be in the opposite direction. Note it.

Change the value of Q, keeping $(P + Q)$ constant at 10000 ohms. Take a number of readings for the throw. In each case, reverse the commutator and get throws on both sides of the centre.

In two or three cases, allow the coil to oscillate after the throw is produced and note the consecutive deflections, five or six, on both sides. From these, the logarithmic decrement can be calculated.

While the coil is oscillating, find the time taken for, say, 5 oscillations with a stop-watch and calculate the period. Take two or three readings and find their mean.

Note :—In a ballistic galvanometer, there is very little damping. So, when the coil is deflected, it will not come to rest soon. It will be oscillating too and fro without appreciable change in amplitude. To bring it to rest, an ordinary tap-key is connected in parallel with the galvanometer. By tapping it, the coil of the galvanometer can be short-circuited and brought to rest quickly.

Steady deflection and constant of the galvanometer :—Remove the condenser connections. In place of Q in the main circuit connect a resistance box of range 1 to 100 ohms. Connect the ends of this box to a resistance box R of range 1 to 5,000 ohms and the galvanometer through the commutator, as in the diagram.

Unplug 1 ohm in Q and 9999 ohms in P. Close the main circuit. Adjust the value of Q, keeping (P + Q) constant

at 10000 ohms, such that a good steady deflection is obtained on the scale. Note the deflection. Reverse the current in the galvanometer and note the deflection.

Unplug resistances from R so as to reduce the deflection to half. The resistance unplugged is equal to the galvanometer resistance G. Take three or four readings.

Calculations :—When a quantity of electricity Q coulombs is discharged through a ballistic galvanometer, the throw produced θ is given by the formula,

$$Q = \frac{K}{AH} \times \frac{T}{2\pi} \times \theta \left(1 + \frac{\lambda}{2}\right)$$

if the galvanometer is a moving coil instrument. K is the restoring couple per unit twist, A, the area of the coil, H, the intensity of the magnetic field, T, the period of the galvanometer and λ , the logarithmic decrement.

$\frac{K}{AH}$ is a constant for the galvanometer and can be determined by passing a steady current i through it and noting the steady deflection ϕ . Then

$$i = \frac{K}{AH} \times \phi$$

or

$$\frac{K}{AH} = \frac{i}{\phi}$$

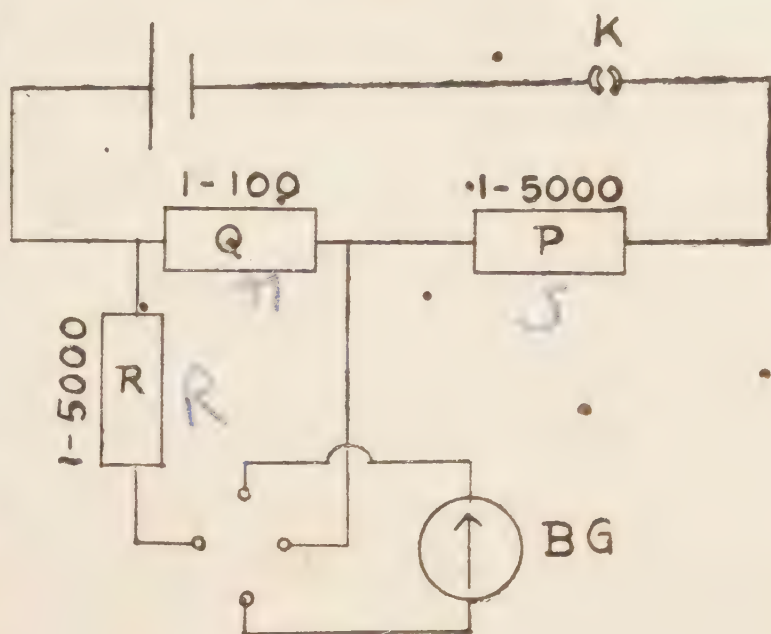


Fig. 205

λ is the logarithmic decrement. It is determined by noting consecutive deflections on both sides. If $d_1, d_2, \dots, d_n$ are consecutive deflections on both sides, it can be shown that,

$$\text{Log}_e d_1 - \text{Log}_e d_n = n \lambda.$$

where d_n is the n th deflection and λ the logarithmic decrement.

$$\begin{aligned} \therefore \lambda &= \frac{\text{Log}_e d_1 - \text{Log}_e d_n}{n} \\ &= \frac{\text{Log } d_1 - \text{Log } d_n}{0.4343 \times n}. \end{aligned}$$

$\frac{K}{AH}$, T , θ , and λ being known, Q can be calculated.

If a condenser of capacity C is charged by the application of a P.D. of V volts, the quantity of electricity Q stored in it is given by

$$Q = VC.$$

This can be discharged through the ballistic galvanometer. From the kick, Q is calculated. If V is known, C can be calculated.

Tabulate the readings as follows :—

I. Charging and discharging the condenser.

E.M.F. of accumulator = E volts

Total Resistance $P + Q$ ohms	Resistance Q ohms	P.D. between ends of Q $V = \frac{EQ}{P + Q}$ volts	Deflection on scale or throw		
			Left	Right	Mean θ

II. Period of oscillation = T seconds.

III. Logarithmic decrement

Deflection on scale		Logarithmic decrement $\lambda = \frac{\text{Log } d_1 - \text{Log } d_n}{0.4343 \times n}$
Left	Right	
d_1	d_2	
d_3	d_4	
d_5	d_6	
d_7	d_8	
Mean ...		

III. Steady deflection :—

Total Resistance $P_1 + Q_1$ ohms	Resistance Q_1 ohms	Deflection on scale			Resistance (R_g) unplugged in R to produce half deflection ohms	
		Left	Right	Mean ϕ	Left	Right

Current i in galvanometer is given by, $i = \frac{E Q_1}{(P_1 + Q_1) R_g}$, where R_g is the galvanometer resistance. Now,

$$i = \frac{K}{AH} \times \phi,$$

$$\frac{K}{AH} = \frac{E Q_1}{(P_1 + Q_1) R_g \times \phi}.$$

From the known values of E , Q_1 , $(P_1 + Q_1) R_g$ and ϕ , calculate $\frac{K}{AH}$

Now,

$$V \times C = \frac{K}{AH} \times \frac{T}{2\pi} \times \theta \left(1 + \frac{\lambda}{2}\right)$$

Substitute the known values of V , $\frac{K}{AH}$, T , θ and λ , and calculate the absolute capacity C .

Note :—An approximate damping correction can be applied as follows. If d_1 and d_2 are two consecutive deflections on the *same side* of the centre, the damping correction is $\left(\frac{d_1}{d_2}\right)^{\frac{1}{2}}$.

This is accurate enough for most experiments.

EXPERIMENT 95

BALLISTIC GALVANOMETER

COMPARISON OF MUTUAL INDUCTANCES

Aim :—To compare the co-efficients of mutual induction of two coils, using a ballistic galvanometer.

Apparatus required :—Two pairs of mutual induction coils, accumulator, two resistance boxes of range 1–5000 ohms, ballistic galvanometer, commutator, plug key.

Procedure :—Connect one coil in each pair in series with the accumulator through a commutator, to form the *main* circuit.

Connect the other coil in each pair in series with two resistance boxes P, Q of range 1 to 5000 ohms, to form the *secondary* circuit.

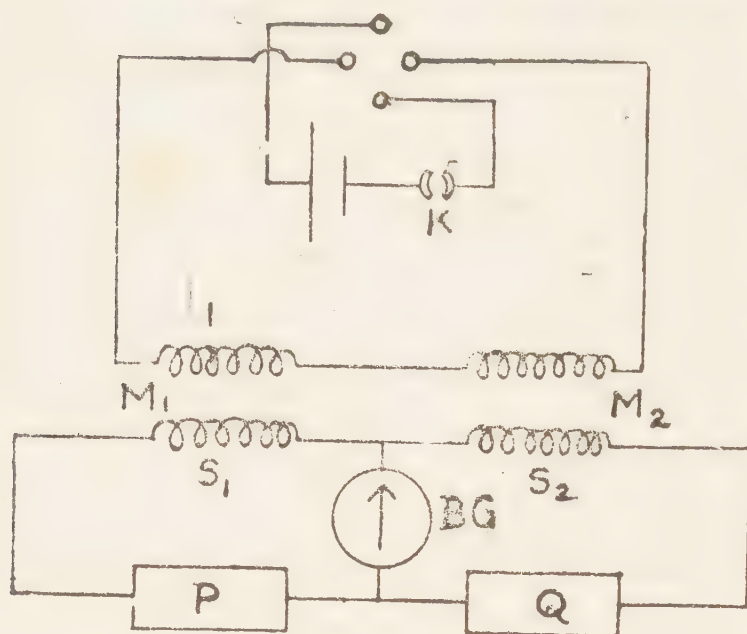


Fig. 206

Connect the ballistic galvanometer between the junction of the two coils and the junction of the two resistance boxes in the secondary circuit, as shown in the circuit diagram.

Close the main circuit.

Adjust the values of the resistances in P and Q, such that, when the commutator is reversed, there is no kick in the galvanometer.

Let P_1 be the resistance unplugged in box P and Q_1 in box Q. Let S_1 and S_2 be the resistances of the coils in the respective branches. Let M_1 and M_2 be the co-efficients of mutual induction of the two pairs of coils. Then, it can be shown that, when there is nil deflection or balance,

$$\frac{M_1}{M_2} = \frac{P_1 + S_1}{Q_1 + S_2}.$$

Adjust the resistances in P and Q such that there is again nil deflection when the commutator is reversed. Let the resistances unplugged be P_2 and Q_2 respectively. Then,

$$\frac{M_1}{M_2} = \frac{P_2 + S_1}{Q_2 + S_2}.$$

Combining the two, you get,

$$\frac{M_1}{M_2} = \frac{P_2 - P_1}{Q_2 - Q_1}.$$

This eliminates the resistances of the coils

Take a number of readings.

Tabulate the results as follows :—

Resistance in box P ohms	Resistance in box Q ohms	$\frac{M_1}{M_2}$
P_1 P_2 P_3 P_4	Q_1 Q_2 Q_3 Q_4	$\frac{P_3 - P_1}{Q_3 - Q_1}$ $\frac{P_4 - P_2}{Q_4 - Q_2}$
Mean		

$\therefore$ Mean value of $\frac{M_1}{M_2} =$

EXPERIMENT 96

BALLISTIC GALVANOMETER

: ABSOLUTE CO-EFFICIENT OF MUTUAL INDUCTION

Aim :—To determine the absolute co-efficient of mutual induction of a pair of coils using the ballistic galvanometer.

Apparatus required :—Accumulator, a rheostat, ballistic galvanometer, resistance box of range 1 to 5000 ohms, a standard low resistance of about 0.1 ohm, a pair of mutual induction coils, a double-successive or sequence key, a four segment commutator, a plug key.

Procedure :—Connect the accumulator in series with a rheostat, one of the mutual induction coils, the standard low resistance and a plug key in series to form the *primary* circuit.

Connect the other coil in series with a

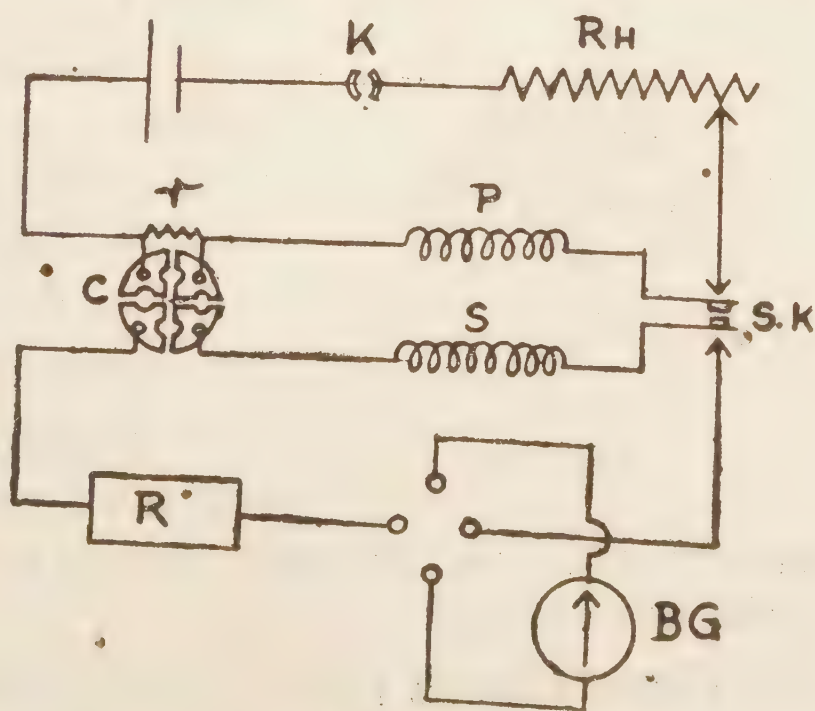


Fig. 207

resistance box and the ballistic galvanometer through a commutator to form the *secondary* circuit.

Introduce the double-successive or sequence key in the two circuits. Incorporated in it, there are two tap keys K_1 , K_2 , insulated from each other but arranged such that a single action closes both keys. One of the keys is included in the primary circuit and the other in the secondary circuit, such that when the key is pressed, the secondary circuit is closed first and then, the primary.



Fig. 208

When it is released, the primary circuit is broken and then the secondary circuit. If the secondary circuit is not broken immediately after a quantity of electricity is discharged through it, there will be considerable damping. Consequently the throw produced will be reduced.

Link the two circuits, using the four segment commutator C. It consists of four metallic blocks 1, 2, 3 and 4 with two plugs for inter-connection. Blocks 1 and 2, 3 and 4 may be connected or 1 and 3, 2 and 4 by changing the position of the plugs (figs. 210 and 211). Connect the ends of the low resistance r to blocks 1 and 2. Connect blocks 3 and 4 to the secondary circuit. If the plugs connect 1 and 2, 3 and 4, the two circuits become independent. If the plugs are changed to connect 1 and 3, 2 and 4, then the ends of resistance r get connected to the secondary circuit.

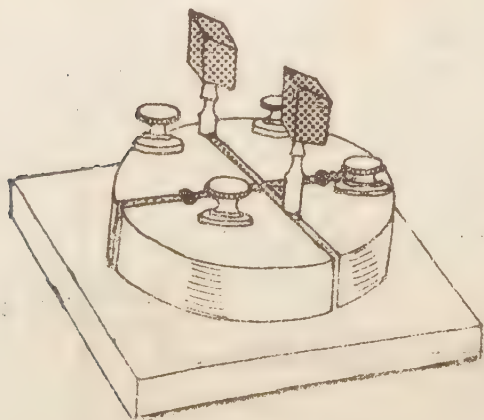


Fig. 210

If a metallic commutator is not available, a block of ebonite or paraffin with four mercury cups in it and two metallic cross links can be used.

Connect blocks 1 and 2, 3 and 4 of the commutator so as to have two independent circuits. Keep the maximum resistance in

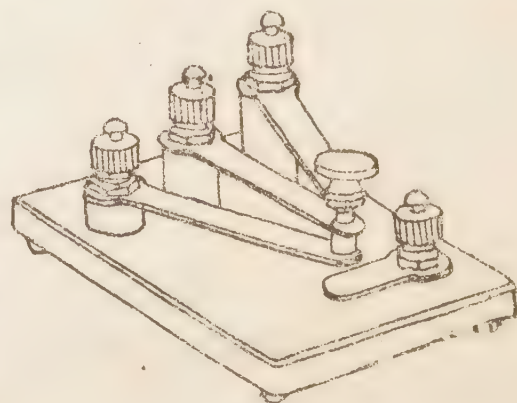


Fig. 209

the rheostat. Close the main circuit with the plug key K. Press the sequence key. The spot of light on the scale will first be deflected. When the spot of light on the scale comes back to zero and is steady, release the key. There will be a throw in the opposite direction. The throw produced when the key is released will be much greater than the throw produced when the key is closed. Adjust the rheostat in the primary circuit and the resistance in box R, so that the deflection is large. Note the throw. Note also the consecutive deflection of the spot of light on the scale on the *same side*.

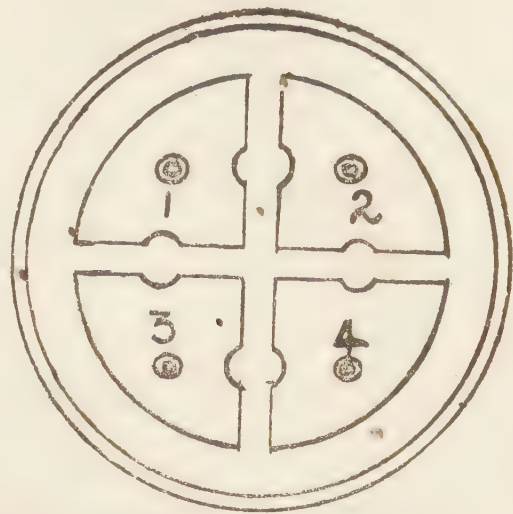


Fig. 211

Reverse the commutator connected to the galvanometer. Press the sequence key. Release it when the spot of light is steady at zero. The throw produced will be in the opposite direction. Note the throw and also the consecutive deflection on the scale on the same side,

Change the plugs in the block commutator so as to connect 1 and 3, 2 and 4. As a consequence, the resistance r gets included in the secondary circuit. Due to the P. D. between the terminals of r , there will be a steady deflection in the galvanometer. Note it. Reverse the current and note the deflection.

The resistance r must be such that the steady deflection is almost the same as the throw.

Let i be the steady current in the main circuit. On releasing the sequence key, a quantity of electricity $\frac{Mi}{R_1}$ will pass through the secondary coil due to the mutual induction between the coils, where M is the co-efficient of mutual induction and R_1 is the total resistance in the secondary circuit.

If the throw produced in the galvanometer by this quantity of electricity passing through it is θ , then

$$\frac{Mi}{R_1} = \frac{K}{AH} \times \frac{T}{2\pi} \times \theta \left(1 + \frac{\lambda}{2} \right) \dots\dots\dots(i)$$

for a moving coil galvanometer.

Owing to the current i in the primary circuit, the P. D. between the terminals of r is ir . Let this produce a steady deflection ϕ in the galvanometer. Then,

$$\frac{ir}{R_1} = \frac{K}{AH} \times \phi \quad \dots\dots\dots(ii)$$

Dividing (i) by (ii), you get,

$$\frac{M}{r} = \frac{T}{2\pi} \times \frac{\theta}{\phi} \left(1 + \frac{\lambda}{2}\right)$$

$$\therefore M = \frac{r \times T}{2\pi} \times \frac{\theta}{\phi} \left(1 + \frac{\lambda}{2}\right).$$

Instead of the correction $\left(1 + \frac{\lambda}{2}\right)$ for the damping, the simpler correction can be applied. If θ is the first throw, and θ_1 the consecutive deflection on the same side, the damping correction is $\left(\frac{\theta}{\theta_1}\right)^{\frac{1}{4}}$

$$\therefore M = \frac{r \times T}{2\pi} \times \frac{\theta}{\phi} \times \left(\frac{\theta}{\theta_1}\right)^{\frac{1}{4}}.$$

Repeat the experiment, altering the resistance in the rheostat and in the box R . In each case, note the throw θ and the steady deflection ϕ . To enable you to apply correction for damping, whenever you note the throw θ , note also the consecutive deflection θ_1 on the same side.

With a stop-watch, find the period of oscillation of the coil.

Tabulate the readings as follows :—

Value of standard low resistance = r ohms

Period of oscillation of galvanometer coil = T secs.

Throws						Steady deflection			$M = \frac{rT}{2\pi} \times \frac{\theta}{\phi} \times \left(\frac{\theta}{\theta_1}\right)^{\frac{1}{4}}$
Left		Right		Mean of the two		Left	Right	Mean ϕ	
d	d ₁	d	d ₁	θ	θ_1				
Mean									

$\therefore$ Mean co-efficient of mutual induction =

EXPERIMENT 97

BALLISTIC GALVANOMETER

INTERNAL RESISTANCES OF CELLS

Aim :—To determine the internal resistance of a cell using a condenser and ballistic galvanometer.

Apparatus required :—Lechlanche's cell, Daniel's cell, condenser, ballistic galvanometer, resistance box of range 1 to 100 ohms, charge and discharge key, commutator, two plug keys.

Procedure :—Connect the Lechlanche's cell (or Daniel's cell), a condenser, a plug key and the charge and discharge key in series. Use the common terminal X and one of the other terminals Y of the key.

Connect in parallel with the cell a resistance box R of range 1 to 100 ohms and a plug key.

Connect the ends of the condenser through the terminal Z of the condenser key to the ballistic galvanometer through the commutator.

Check up the connections with the circuit diagram.

Close the circuit of the cell. Charge the condenser by bringing X in contact with Y. Discharge it through the galvanometer by bringing X in contact with Z. Note the throw.

Reverse the commutator. Charge the condenser again and discharge it through the galvanometer. Note the throw. Find the mean. Let it be θ .

Unplug 20 ohms from the resistance box R and close the parallel circuit.

Charge the condenser as before and discharge it through the galvanometer. Note the throw. Reverse the commutator. Charge the condenser again and discharge it. Note the throw. Find the mean. Let it be θ_1 . θ_1 will be less than θ .

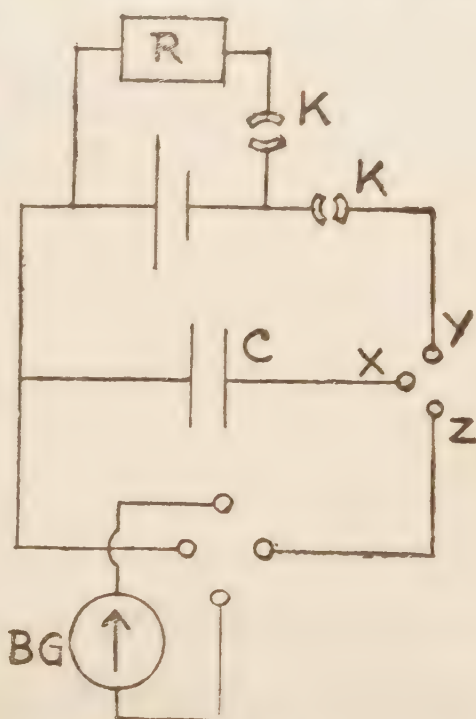


Fig. 212

Repeat the experiment unplugging 15, 12, 10, 7, 5 and 2 ohms in the resistance box. Note the throws on the left and on the right in each case, when the condenser is charged and discharged.

Find the mean throw corresponding to each resistance.

Let E be the E.M.F. and r the internal resistance of the cell. Let C be the capacity of the condenser. If θ is the mean throw when the condenser is charged and discharged,

$$E C \propto \theta.$$

When the cell is short-circuited with a resistance R , the condenser is charged only by the P.D. between the terminals of R . If i is the current in the circuit and θ_1 the mean throw when the condenser is charged and discharged,

$$i R \times C \propto \theta_1.$$

$$\text{Now, } E = i(R + r) = iR + ir.$$

$$\therefore \frac{i(R + r) \times C}{iR \times C} = \frac{\theta}{\theta_1}$$

$$\therefore \frac{R + r}{R} = \frac{\theta}{\theta_1}$$

$$\therefore \frac{r}{R} = \frac{\theta - \theta_1}{\theta_1}$$

$$\therefore r = \left(\frac{\theta - \theta_1}{\theta_1} \right) \times R$$

From the known values of R , θ and θ_1 , calculate r .

Tabulate the results as follows:—

Resistance R	Throw			$r = \left(\frac{\theta - \theta_1}{\theta_1} \right) \times R$
	Left	Right	Mean	
∞	θ'	θ''	θ	$\left(\frac{\theta - \theta_1}{\theta_1} \right) R$
20 ohms	θ_1'	θ_1''	θ_1	
15 ,,				
12 ,,				
10 ,,				
5 ,,				
2 ,,				

EXPERIMENT 98

BALLISTIC GALVANOMETER

REDUCTION FACTOR OF A TANGENT GALVANOMETER

Aim :—To measure current and determine the reduction factor of a tangent galvanometer, using a condenser and ballistic galvanometer.

Apparatus required :—Accumulator, rheostat, a standard resistance of 1 ohm, a standard condenser, a freshly prepared Daniel's cell, ballistic galvanometer, tangent galvanometer, double-throw key, charge and discharge key, two commutators, plug key.

Procedure :—Connect in series an accumulator, the rheostat, the standard one ohm resistance, a plug key and the tangent galvanometer through a commutator, to form the primary circuit. Use the 5 or 10 turns coil of the tangent galvanometer.

Connect the ends of the standard condenser to the common terminals A, B of the double-throw key through the charge and discharge key.

Connect the ends of the standard resistance r to one pair of terminals C, D and the Daniel's cell to the other pair of terminals E, F of the double-throw key.

Connect the ends of the condenser to the ballistic galvanometer through the charge and discharge key and a commutator.

Check up the connections with the circuit diagram.

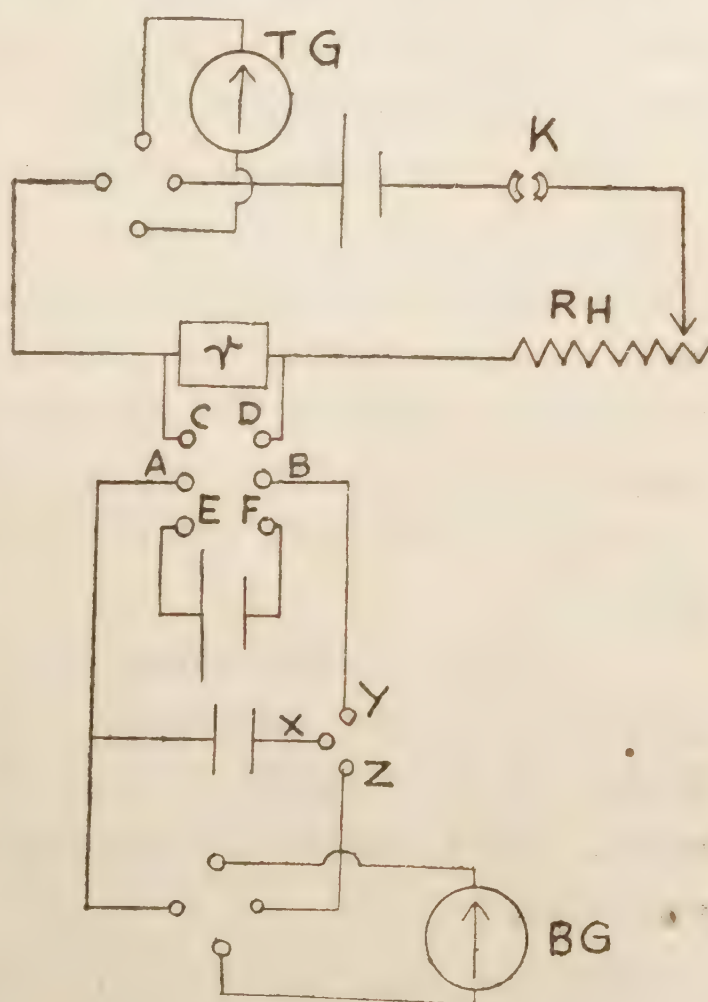


Fig. 213

. Have the maximum resistance in the rheostat. Close the primary circuit. Adjust the rheostat, so as to get a deflection of about 40° in the tangent galvanometer. Note the deflection. Reverse the current and note the deflection.

With the double-throw key, introduce the standard resistance in the circuit of the condenser. Charge the condenser with the P.D. between the terminals of the resistance. Discharge it through the galvanometer and note the throw. Note the consecutive deflection on the same side for calculating the correction for damping.

Reverse the commutator. Charge the condenser again and discharge it through the galvanometer. The throw will now be in the opposite direction. Note the throw. Note also the consecutive deflection on the same side. Find the mean of the two throws.

Adjust the rheostat so as to produce a deflection of 45° in the tangent galvanometer. Reverse the current and note the deflection. Find the mean deflection.

Charge the condenser as before and discharge it through the galvanometer. Note the throw. Reverse the commutator. Charge the condenser again and discharge it. Note the throw, which will be in the opposite direction. Find the mean. Repeat the experiment after adjusting the rheostat for a deflection of 50° in the tangent galvanometer. Whenever a throw is noted, note also the consecutive deflection on the same side, for calculating the damping correction.

Using the double-throw key, introduce the Daniel's cell in the circuit of the condenser. Charge the condenser with the E.M.F. of the Daniel's cell and discharge it through the galvanometer. Note the throw and the consecutive deflection on the same side.

Reverse the commutator. Charge the condenser again and discharge it. Note the throw and the consecutive deflection. Find the mean throw.

If θ is the mean deflection in the tangent galvanometer, the current in the circuit is $K \tan \theta$, where K is the reduction factor. Hence, the P.D. between the terminals of the standard resistance

r is $r K \tan \theta$. When the condenser is charged by this P.D., let the mean throw be d_1 , in the ballistic galvanometer. Let d_2 be the consecutive deflection on the same side. Let C be the capacity of the condenser. Then,

$$r K \tan \theta \times C = \frac{K}{AH} \times \frac{T}{2\pi} \times d_1 \times \left(\frac{d_1}{d_2}\right)^{\frac{1}{4}} \dots\dots\dots(i)$$

When the condenser is charged by the Daniel's cell of E.M.F. E , let the mean throw be d' and the consecutive deflection on the same side d'' . Then,

$$E \times C = \frac{K}{AH} \times \frac{T}{2\pi} \times d' \times \left(\frac{d'}{d''} \right)^{\frac{1}{4}} \dots\dots\dots(ii)$$

Dividing (i) by (ii) and eliminating the common factors,

$$\frac{r \kappa \tan \theta}{E} = \frac{d_1 \times \left(\frac{d_1}{d_2}\right)^{\frac{1}{4}}}{d' \times \left(\frac{d'}{d''}\right)^{\frac{1}{4}}}$$

$$\therefore K = \frac{E}{r \tan \theta} \times \frac{d_1}{d'} \times \frac{\left(\frac{d_1}{d_2}\right)^{\frac{1}{4}}}{\left(\frac{d'}{d''}\right)^{\frac{1}{4}}}$$

If the Daniel's cell is fresh, its E.M.F. will be 1.08 volts. From the known values of E , r , θ , d_1 , d_2 , d' , and d'' , K can be calculated.

Note :—Since the damping correction is constant, $\left(\frac{d_1}{d_2}\right)^{\frac{1}{4}}$

must be equal to $\left(\frac{d'}{d''}\right)^{\frac{1}{4}}$

Tabulate the results as follows :—

E.M.F. of Daniel's cell $= 1.08$ volts.

Standard resistance $\quad \quad \quad = r$ ohms

No. of turns in tangent galvanometer =

Deflection in T.G.				Throw due to P.D. in standard resistance			Throw due to E.M.F. of Daniel's cell			Reduction factor K.
Left	Right	Mean θ	Tan θ	Left	Right	Mean	Left	Right	Mean	
						d_1 d_2				d' d''

$$K = \frac{E}{r \tan \theta} \times \frac{d_1}{d_2} \times \frac{\left(\frac{d_1}{d_2}\right)^{\frac{1}{4}}}{\left(\frac{d'}{d''}\right)^{\frac{1}{4}}}$$

$\therefore$ Mean Reduction Factor $K =$

EXPERIMENT 99

BALLISTIC GALVANOMETER

DETERMINATION OF CONSTANT

Aim :—To determine the constant or quantity sensitivity of a ballistic galvanometer using (1) a standard condenser, (2) Hibbert's magnetic standard, and (3) a standard solenoid ; and by noting (4) the steady deflection.

(A) Standard Condenser Method

Apparatus required :—A freshly prepared Daniel's cell or accumulator, standard condenser, two resistance boxes of range 1 to 5000 ohms, ballistic galvanometer, commutator, charge and discharge key, plug key.

Procedure :—Connect the cell of *known* E.M.F. in series with the two resistance boxes P and Q and a plug key.

Connect the ends of box Q to the standard condenser through the charge and discharge key.

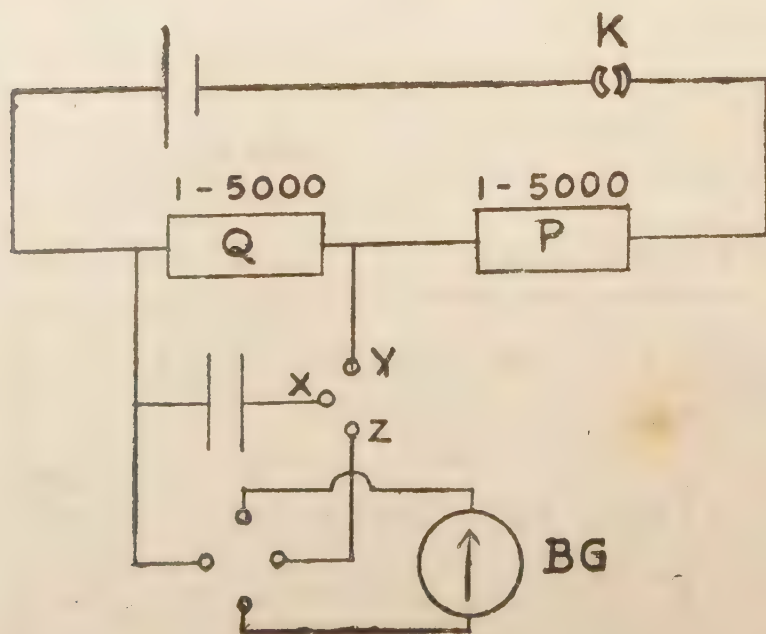


Fig. 214

Connect the terminals of the standard condenser to the ballistic galvanometer through a commutator and the condenser key.

Check up the connections with the circuit diagram.

Unplug 5000 ohms in each of the boxes P and Q. Close the main circuit.

Charge the condenser with the P.D. at the terminals of Q, using the condenser key. Discharge it through the galvanometer. Note the throw and the consecutive deflection on the same side.

Reverse the commutator. Charge the condenser again and discharge it through the galvanometer. Note the throw and the consecutive deflection. Let the mean throw be θ_1 and the mean consecutive deflection be θ_2 .

Let E be the known E.M.F. of the cell. Then the P.D. between the terminals of Q is $\frac{EQ}{P+Q}$. The quantity of electricity in the condenser when it is charged is $\frac{EQ}{P+Q} \times C$, where C is the capacity of the condenser. If θ_1 is the mean throw due to the discharge and θ_2 , the mean consecutive deflection,

$$Q = \frac{EQ}{P+Q} \times C = \frac{K}{AH} \times \frac{T}{2\pi} \times \theta_1 \times \left(\frac{\theta_1}{\theta_2}\right)^{\frac{1}{4}}$$

$$= G \times \theta_1 \times \left(\frac{\theta_1}{\theta_2}\right)^{\frac{1}{4}}$$

where G is the galvanometer constant.

$$\therefore G = \frac{EQ}{(P+Q)} \times \frac{C}{\theta_1 \times \left(\frac{\theta_1}{\theta_2}\right)^{\frac{1}{4}}}$$

From the known values of E, Q, P, C, θ_1 and θ_2 , G can be calculated. It is the quantity sensitivity of the galvanometer.

Alter the value of Q, keeping (P + Q) constant at 10000 ohms, and repeat the experiment. Take three or four sets of readings.

Tabulate the readings as follows :—

E.M.F. of cell = E volts
Standard condenser = C micro-farads.

Resis- tance		Throw on scale			Consecutive deflection			$G = \frac{EQC}{(P+Q) \times \theta_1 \times \left(\frac{\theta_1}{\theta_2}\right)^{\frac{1}{4}}}$
P + Q	Q	Left	Right	Mean θ_1	Left	Right	Mean θ_2	
Mean ...								

Mean value of the galvanometer constant G } = coulombs per cm.

(B) Hibbert's Magnetic Standard

Apparatus required :—Hibbert's magnetic standard, resistance box of range 1 to 500 ohms, ballistic galvanometer, commutator.

Description :—The Hibbert's magnetic standard consists of a block of hard steel with a cylindrical groove in the middle. It is magnetised such that the lines of force in the gap are all radial. A coil of insulated wire of a definite number of turns is wound over a thin brass tube, which can freely drop through the groove. The ends of the coil are connected to two terminals on a lid covering the top of the tube. The brass tube can be raised above the groove and kept in position by a lever. When the lever is pressed, it releases the tube, which drops into the groove.

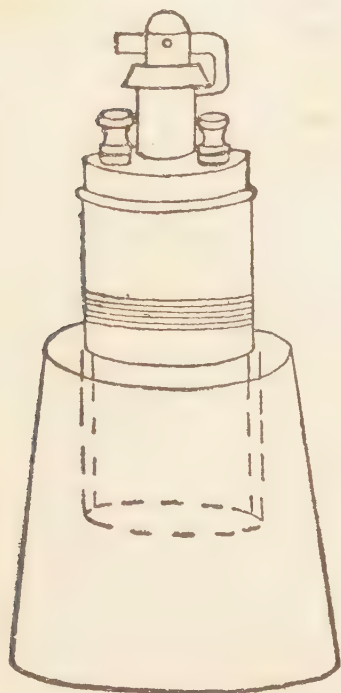


Fig. 215

When the brass tube is suddenly dropped in the groove, the coil of wire cuts the lines of force and an E.M.F. is induced in it. A momentary current passes through it. The quantity of current passing through it during the drop is equal $\frac{Nn}{10^8 \times R}$ coulombs, where N is the magnetic flux through the coil, n the number of turns of coil and R , the resistance in the circuit.

Procedure :—Connect the terminals of the coil in the Hibbert's

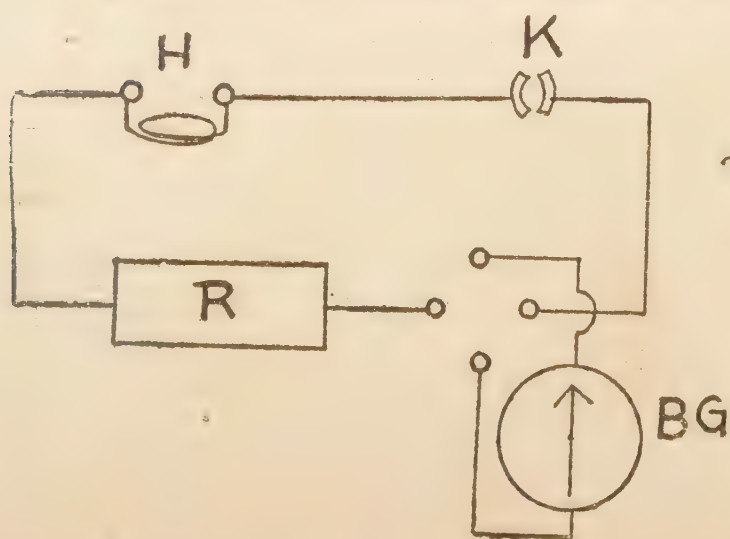


Fig. 216

standard in series with a resistance box, a plug key and the ballistic galvanometer through a commutator.

Unplug about 50 to 100 ohms in the resistance box. Close the circuit. Raise the tube and drop it into the groove. Note the throw on the scale. Adjust the resis-

tance in the box so as to get a suitable throw. Note the resistance R_1 and the throw.

Reverse the commutator. Raise the tube and drop it again. Note the throw. Find the mean of the two. Let it be θ_1 .

Alter the resistance in the box to R_2 . Note the mean throw on the left and on the right. Let it be θ_2 .

Take a number of sets of readings. Note the consecutive deflections in a few cases, for calculating the damping correction.

$$Q = \frac{Nn}{10^8 \times R} = G \times \theta \left(1 + \frac{\lambda}{2} \right)$$

$$\therefore R = \frac{Nn}{10^8 \times G \times \theta \left(1 + \frac{\lambda}{2} \right)}$$

$$\text{Now, } R_1 + R_g = \frac{Nn}{10^8 \times G \times \theta_1 \left(1 + \frac{\lambda}{2} \right)}$$

$$\text{and } R_2 + R_g = \frac{Nn}{10^8 \times G \times \theta_2 \left(1 + \frac{\lambda}{2} \right)}$$

where R_g is the resistance of the galvanometer.

$$\therefore (R_2 - R_1) = \frac{Nn}{10^8 \times G \times \left(1 + \frac{\lambda}{2} \right)} \left(\frac{1}{\theta_2} - \frac{1}{\theta_1} \right)$$

$$\therefore G = \frac{Nn}{10^8 \times \left(1 + \frac{\lambda}{2} \right) \times (R_2 - R_1)} \left(\frac{1}{\theta_2} - \frac{1}{\theta_1} \right)$$

From the known values of N , n , R_2 , R_1 , θ_1 , θ_2 and the damping correction, calculate G , the galvanometer constant. If θ_1 is the first throw and θ_1' , the consecutive deflection, the damping correction is $\left(\frac{\theta_1}{\theta_1'} \right)^{\frac{1}{4}}$. This can be substituted in place of $\left(1 + \frac{\lambda}{2} \right)$ in the formula.

(C) Solenoid Inductor Method

Apparatus required:—Two or three accumulators, ammeter, standard solenoid, rheostat, ballistic galvanometer, resistance box, two commutators, plug key.

Description :—The standard solenoid inductor consists of a long solenoid, one metre in length and about 4 to 5 cms. in diameter. 1000 turns of insulated wire are wound uniformly over it. At the middle, a secondary coil consisting of 100 turns is wound over the primary coil. Usually there are tappings for 10, 20, 30 and 50 turns on the secondary coil. The magnetic field at the middle of the primary coil, when a current is passed through it, is uniform. The magnetic intensity is given by $\frac{4\pi ni}{10}$ gaussses, where i is the current in amperes and n , the number of turns in the primary. So, the magnetic flux in the secondary is $\frac{4\pi ni}{10} \times \pi r^2 N$, where N is the number of turns in the secondary and πr^2 its area of cross-section.

Procedure :—Connect a battery of two or three accumulators in series with an ammeter, a rheostat, a plug key and the primary of the solenoid S through a commutator. When the commutator is reversed, the current will be reversed only in the primary coil of the solenoid.

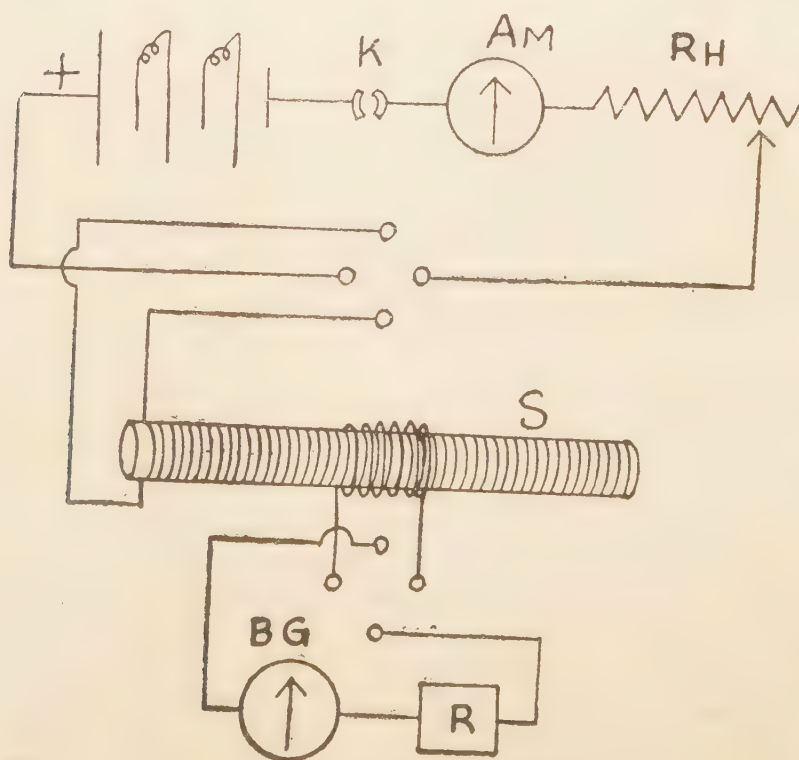


Fig. 217

Connect the terminals of the secondary coil in series with a resistance box R , and the ballistic galvanometer, through a commutator.

Close the primary circuit. Adjust the

rheostat, so that a current of 1 to 2 amperes passes through the primary coil.

Reverse the current in the primary. Adjust the resistance in the galvanometer circuit so as to have a suitable throw. Note the throw.

Reverse the commutator in the galvanometer circuit. Again reverse the current in the primary circuit. Note the throw. Find the mean of the two.

Note the consecutive deflections on the same side, for applying the damping correction.

Alter the resistance in the box in the galvanometer circuit. Note the throws on both sides, when the current is reversed in the primary coil.

Change the current in the primary circuit. Repeat the experiment. Take three or four sets of readings.

The change of flux in the secondary coil when the current is reversed in the primary is

$$2 \times \frac{4\pi ni}{10} \times \pi r^2 N.$$

Hence, the quantity of electricity passing through the secondary coil is given by

$$Q = \frac{8\pi^2 r^2 i n N}{10 \times 10^8 \times R} \text{ coulombs.}$$

where R is the total resistance in the galvanometer circuit.

If θ is the throw produced in a moving coil ballistic galvanometer,

$$Q = \frac{K}{AH} \times \frac{T}{2\pi} \times \theta \left(1 + \frac{\lambda}{2}\right).$$

$$\therefore \left(\frac{K}{AH} \times \frac{T}{2\pi}\right) \text{ or } G = \frac{8\pi^2 r^2 i n N}{10^9 \times R \times \theta \left(1 + \frac{\lambda}{2}\right)}$$

From the known values of r , i , n , N , R , θ and λ , the galvanometer constant $\left(\frac{K}{AH} \times \frac{T}{2\pi}\right)$ or G can be calculated.

If the resistance of the galvanometer is R_g , the total resistance R in the galvanometer circuit is $R_1 + R_g$, where R_1 is the resistance unplugged from the box. If R_g is known, its value can be substituted. Otherwise it can be eliminated from two different values of $(R_1 + R_g)$ and $(R_2 + R_g)$.

$$(R_1 + G) = \frac{8\pi^2 r^2 i n N}{10^9 \times G \times \theta_1 \left(1 + \frac{\lambda}{2}\right)}$$

$$(R_2 + R_g) = \frac{8\pi^2 r^2 i n N}{10^9 \times G \times \theta_2 \left(1 + \frac{\lambda}{2}\right)}$$

Subtracting and rearranging,

$$G = \frac{8\pi^2 r^2 i n N}{10^9 \times (R_2 - R_1) \left(1 + \frac{\lambda}{2}\right)} \times \left(\frac{1}{\theta_2} - \frac{1}{\theta_1}\right)$$

Tabulate the readings as follows :—

No. of turns per cm in primary	=	n
No. of turns in secondary	=	N
Radius of secondary	=	r cm
Current in the primary circuit	=	i amps
Resistance in secondary circuit	=	R_1 ohms
Mean throw	=	θ_1
Mean consecutive deflection	=	θ_1'
Resistance in secondary circuit	=	R_2 ohms
Mean throw	=	θ_2
Mean consecutive deflection	=	θ_2'
Damping correction $\left(1 + \frac{\lambda}{2}\right)$	=	$\left(\frac{\theta_1}{\theta_1'}\right)^{\frac{1}{2}}$
	=	or $\left(\frac{\theta_2}{\theta_2'}\right)^{\frac{1}{2}}$

From these values, calculate the galvanometer constant G.

(D) Steady deflection method.

Apparatus required :—

Accumulator, two resistance boxes of range 1 to 5000 ohms, a resistance box of range 1 to 100 ohms, ballistic galvanometer, plug key, commutator, stop-watch.

Procedure :—

Adopting the potential divider method, described in experiment 90, obtain a steady deflection θ in the

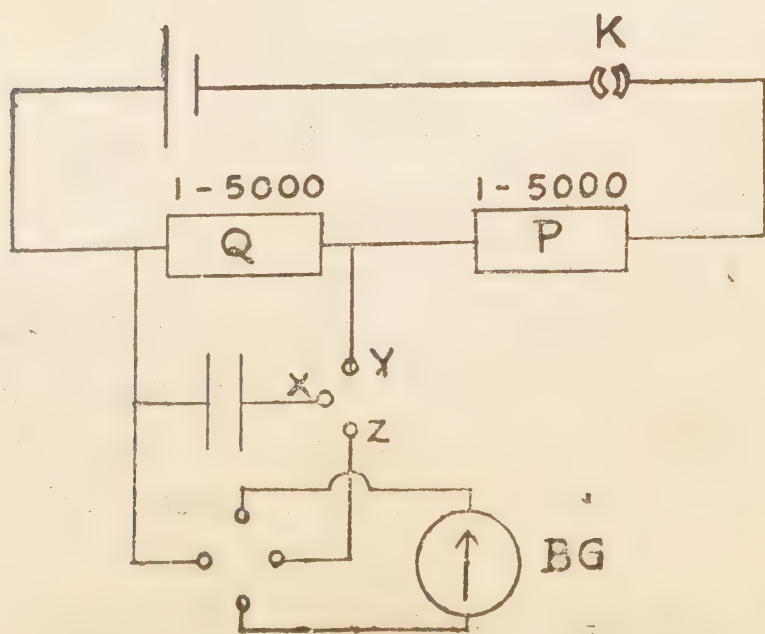


Fig. 218

galvanometer. By the half deflection method, determine the resistance R_g of the galvanometer. The steady current

$$i = \frac{EQ}{(P+Q) R_g} \text{ amps}$$

Now,
$$i = \frac{K}{AH} \times \theta$$

$$\therefore \frac{K}{AH} = \frac{EQ}{(P+Q) R_g} \times \frac{1}{\theta}$$

Allow the coil to oscillate and note the period of oscillation T . The quantity sensitivity G or constant of the ballistic galvanometer is given by,

$$G = \frac{K}{AH} \times \frac{T}{2\pi}$$

Calculate G (coulombs per cm).

E is the E.M.F. of the accumulator. $(P + Q)$ is the total resistance in the main circuit. Q is the resistance, to the ends of which the galvanometer is connected.

Change the value of Q keeping $(P + Q)$ constant. Take a number of readings and calculate G . Find the mean value of G .

EXPERIMENT 100

EARTH INDUCTOR

Aim:—To determine (1) the angle of dip, (2) the vertical component of the Earth's intensity at a place and (3) the constant of a ballistic galvanometer, using an Earth inductor.

Apparatus required:—Earth inductor, ballistic galvanometer, resistance box, tap key.

Description of apparatus:—The Earth inductor consists of a coil of a large number of turns of insulated wire wound over a circular wooden frame, about 30 to 40 cms. in diameter. The circular frame is mounted symmetrically inside a square frame in such a manner, that it could be rotated quickly about a diameter. The square frame is mounted on a stand such that it could be rotated about an axis in its own plane. Thus, the square frame can be adjusted to be vertical or horizontal. When the frame is

vertical, the circular coil can be rotated about a vertical diameter, while, when it is horizontal, the coil can be rotated about a horizontal diameter.

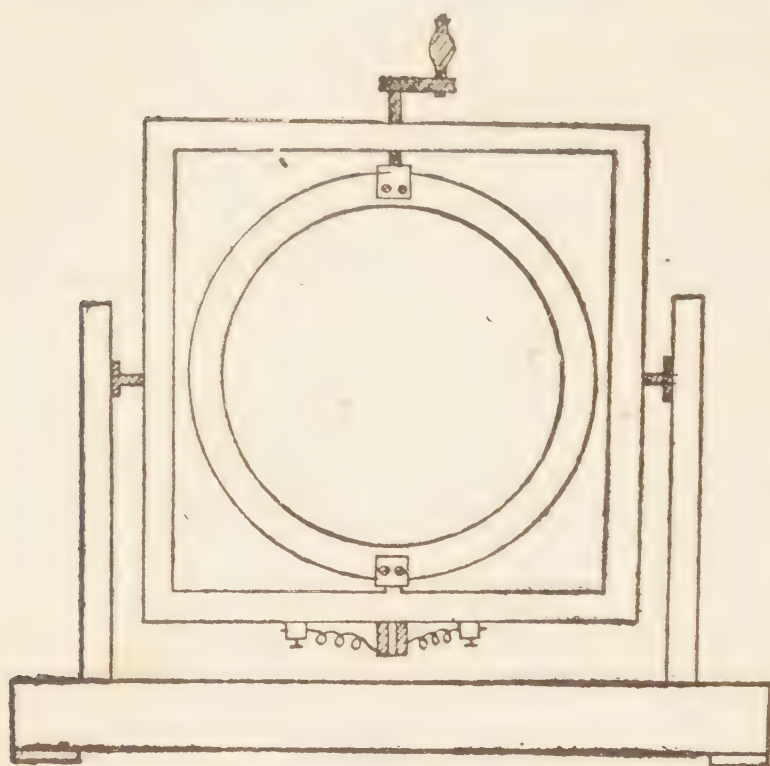


Fig. 219

When the coil is rotated about a vertical axis, it cuts the horizontal flux of the Earth's magnetic field. When it is rotated about a horizontal axis, it cuts the vertical flux of the Earth's field.

The ends of the coil are soldered to two slip rings of brass insulated from each other. Two thin metallic brushes are in contact with them and serve to conduct the induced electric current. They are connected to two fixed terminals.

Procedure :—Connect the Earth inductor in series with a resistance box and a ballistic galvanometer. Adjust the square frame to be vertical. Turn it so as to be at right angles to the magnetic meridian. Turn the coil so that its plane coincides with that of the frame. Give a quick rotation of the coil through 180° . Note the throw on the scale. Give the coil another quick half turn. The throw will now be on the opposite side. Note it. Note also the consecutive deflections on the same side as the first throw, in each case, for calculating the damping correction.

Unplug some resistances from the box and note the throws again, on both sides. Repeat the experiment and take a number of readings.

Adjust the square frame and the coil to be horizontal. Turn it, so that the axis of rotation of the circular coil is in the magnetic meridian. Rotate it through 180° and note the throw. Rotate it through another 180° and note the throw which will be on the opposite side. Take a number of readings, for different resistances in the box.

Note :—It is possible that due to damping, the full throw may not be obtained. If so, include a tap key in the circuit. Keep it pressed when the coil is rotated and release it immediately. The damping will be reduced considerably.

Calculations :—Let A be the area of each turn of the coil and n the number of turns in the coil. When it is rotated about a vertical axis in the manner indicated above, it cuts an effective flux equal to $2nAH$, where H is the horizontal component of the Earth's field.

If R is the total resistance in the circuit, i.e., the resistance of the galvanometer and the resistances unplugged in the box, the quantity of electricity produced Q_1 is given by

$$Q_1 = \frac{2n AH}{R \times 10^8} \text{ coulombs.}$$

If θ is the throw on the scale,

$$Q_1 = G \times \theta \left(1 + \frac{\lambda}{2}\right)$$

where G is the galvanometer constant and $\left(1 + \frac{\lambda}{2}\right)$, the damping correction.

When it is rotated about a horizontal axis, the quantity of electricity produced is similarly given by $Q_2 = \frac{2n AV}{R \times 10^8}$ coulombs, where V is the vertical component of the Earth's field at the place. If ϕ is the throw on the scale,

$$Q_2 = G \times \phi \left(1 + \frac{\lambda}{2}\right).$$

Dip :—

$$\frac{Q_2}{Q_1} = \frac{\frac{2n AV}{R \times 10^8}}{\frac{2n AH}{R \times 10^8}} = \frac{G \times \phi \left(1 + \frac{\lambda}{2}\right)}{G \times \theta \left(1 + \frac{\lambda}{2}\right)}$$

$$\therefore \frac{V}{H} = \frac{\phi}{\theta}$$

If D is the dip at the place

$$\tan D = \frac{V}{H} = \frac{\phi}{\theta}$$

II.
$$\frac{V}{H} = \frac{\phi}{\theta}$$

$$\therefore V = H \times \frac{\phi}{\theta}$$

III.
$$G = \frac{2nAH}{10^8 \times R \times \theta \times \left(1 + \frac{\lambda}{2}\right)}$$

and
$$\frac{2nAV}{10^8 \times R \times \phi \left(1 + \frac{\lambda}{2}\right)}$$

Calculate G from the known values of the other quantities.

EXPERIMENT 101

SEARCH COIL—POLE-STRENGTH OF A MAGNET

Aim :—(1) To investigate the distribution of magnetism along a magnet with a search coil and (2) to determine its pole-strength, using the Hibbert's magnetic standard and a ballistic galvanometer.

Apparatus required :—A bar magnet, Hibbert's magnetic standard, search coil, rheostat, ballistic galvanometer, distance pieces, commutator.

Description :—The search coil consists of a number of turns of insulated copper wire wound over a hollow frame (of some insulating material) which can slide along the magnet. The ends of the wire are connected to two terminals on the frame. Two distance pieces of wood or brass, are provided which can slide over the magnet. They are provided with side screws by which they can be fixed on the magnet at any point on it.

Procedure :—Slip the search coil and the distance pieces over the magnet, one on either side of the search coil. Connect the search coil and the Hibbert's magnetic standard in series with the rheostat and the ballistic galvanometer through a commutator.

Note the throw produced on the galvanometer scale when the coil of the Hibbert's

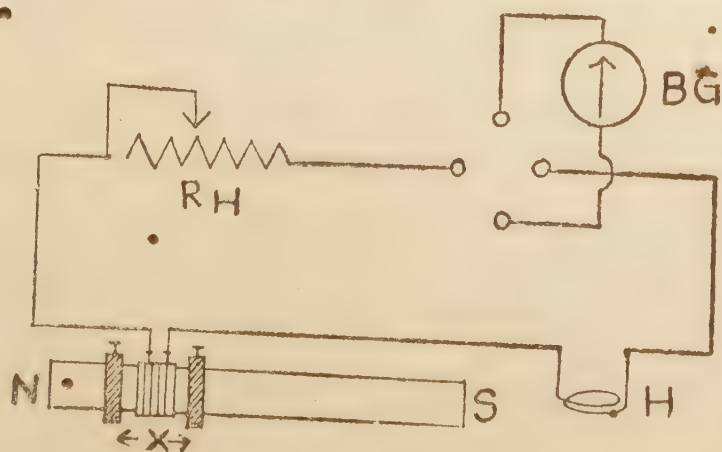


Fig. 220

standard is dropped into the groove. Reverse the commutator and note the throw in the opposite direction. Let the mean throw be θ . Then, the quantity of electricity Q , is given by,

$$Q_1 = G \times \theta \left(1 + \frac{\lambda}{2} \right)$$

If N is the magnetic flux in the Hibbert's standard, n the number of turns of wire in the coil, R the total resistance in the circuit, the quantity of electricity produced Q is given by,

$$Q = \frac{Nn}{R \times 10^8} \text{ coulombs.}$$

$$\therefore \frac{Nn}{R \times 10^8} = G \times \theta \left(1 + \frac{\lambda}{2} \right)$$

(A) Distribution of magnetism along magnet

Remove the distance piece on the magnet near the end. The length of the magnet l is divided into a number of equal steps, x . Then, the length of a step is $\frac{l}{x}$ cms. Fix the other distance piece at a distance of $\frac{l}{x}$ cms from one end. Place the search coil at one end. Jerk it quickly towards the distance piece through $\frac{l}{x}$ cms. Note the throw on the scale. Reverse the commutator. Bring the coil to its original position and again jerk it quickly through the distance. The throw will be in the opposite direction. Note the mean throw. Let it be ϕ_1 .

Move the distance piece through $\frac{l}{x}$ cms and fix it there. Slip the other distance piece over the magnet and fix it at a distance of $\frac{l}{x}$ cms from the other. Jerk the search coil from one of them to the other in the same direction as before. Note the throw. Reverse the commutator and repeat the experiment. Note the throw in the opposite direction. Let the mean throw be ϕ_2 .

Repeat the experiment, moving the distance pieces through $\frac{l}{x}$ cms at a time and cover the whole length of the magnet. Let the mean throws be $\phi_1, \phi_2, \dots \phi_x$ corresponding to each step.

(B) Polestrength of magnet

Remove one of the pieces. Fix the other at the centre of the magnet. Keep the search coil near the centre. Find the throw produced when the search coil is withdrawn quickly from the centre to the end of the magnet. Reverse the commutator.

Repeat the experiment. Find the throw in the opposite direction. Let the mean throw be d_1 .

Repeat the experiment for the other pole. Let the mean throw be d_2 .

If m is the pole strength of the magnet, the magnetic flux cut by each turn of the search coil, when it is quickly withdrawn from the centre to the end is $4\pi m$. If the number of turns in the search coil is s , the total magnetic flux cut is $4\pi m \times s$. The quantity of electricity produced is given by

$$Q = \frac{4\pi m \times s}{R \times 10^8} \text{ coulombs.}$$

Where R is the total resistance in the circuit. If d_1 is the mean throw on the scale,

$$Q = G \times d_1 \times \left(1 + \frac{\lambda}{2}\right)$$

$$\therefore \frac{4\pi m \times s}{R \times 10^8} = G \times d_1 \times \left(1 + \frac{\lambda}{2}\right)$$

It has been shown that

$$\frac{Nn}{R \times 10^8} = G \times \theta \times \left(1 + \frac{\lambda}{2}\right)$$

$\therefore$ Dividing one by the other,

$$\frac{4\pi m \times s}{n} = \frac{d_1}{\theta}$$

$$\therefore m = \frac{Nn d_1}{4\pi s \theta}$$

From the known values of N , n , d_1 , s and θ , calculate m , the pole-strength.

Tabulate the readings as follows :—

I. Distribution of magnetism in magnet

Length of magnet = l cms.

No. of steps = x

$\therefore$ Length of each step = $\frac{l}{x}$ cms.

Distance from end of magnet.	Throw		Mean throw ϕ
	Left	Right	

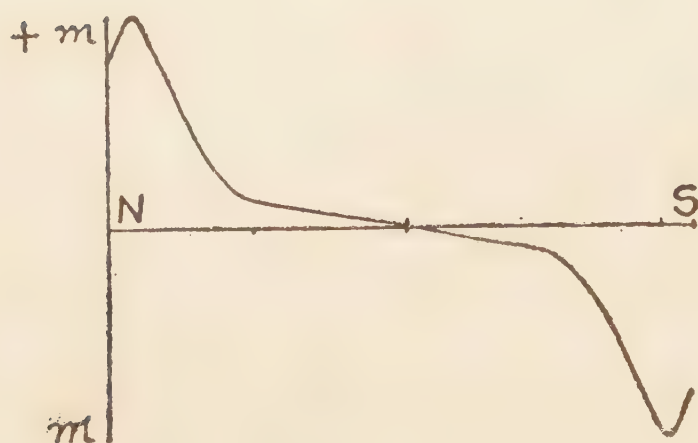


Fig. 221

Draw a graph representing the distance from the end of the magnet on the x axis and the throw on the y axis. The throw will be proportional to the intensity of magnetisation in the region. A curve as shown in the figure will be obtained.

II. Pole-Strength

Number of turns in the coil of the Hibbert's standard } = n

Magnetic flux in Hibberts standard = N

No. of turns in search coil = s

Throw with Hibbert's standard			Throw with search coil		
Left	Right	Mean θ	Left	Right	d_1

$$\therefore m = \frac{Nn d_1}{4 \pi s \theta}$$

Calculate like—wise, the strength of the other pole.

EXPERIMENT 102

COEFFICIENT OF SELF-INDUCTION—
ANDERSON'S METHOD

Aim :—To determine the absolute coefficient of self-induction of a coil by Anderson's method.

Apparatus required :—Post-office box, two resistance boxes of range 1 to 500 ohms (preferably with fractional resistances), self-induction coil, a standard condenser, ballistic galvanometer, accumulator.

Procedure :—Form a Wheat stone's net with the three arms P, Q, R, of the P.O. box, and the self-induction coil L and one of the resistance boxes S in the fourth arm.

Let the junctions be A, B, C, D. Connect A and C to the ballistic galvanometer through the other resistance box T and the tap key K_1 .

Connect B and D to the accumulator through the tap-key K_2 .

Connect the ends of the condenser to B and the junction between the galvanometer and the resistance box T.

Unplug resistances in P, Q, R and S. Press the battery key k_2 , and then the galvanometer key k_1 and adjust the values of P, Q, R and S for nil deflection in the galvanometer.

Adjust next the resistance in the box T such that there is no deflection in the galvanometer, when the battery key k_2 is pressed, or released, keeping k_1 pressed.

Thus, both for steady currents and inductive currents, there is nil deflection in the galvanometer.

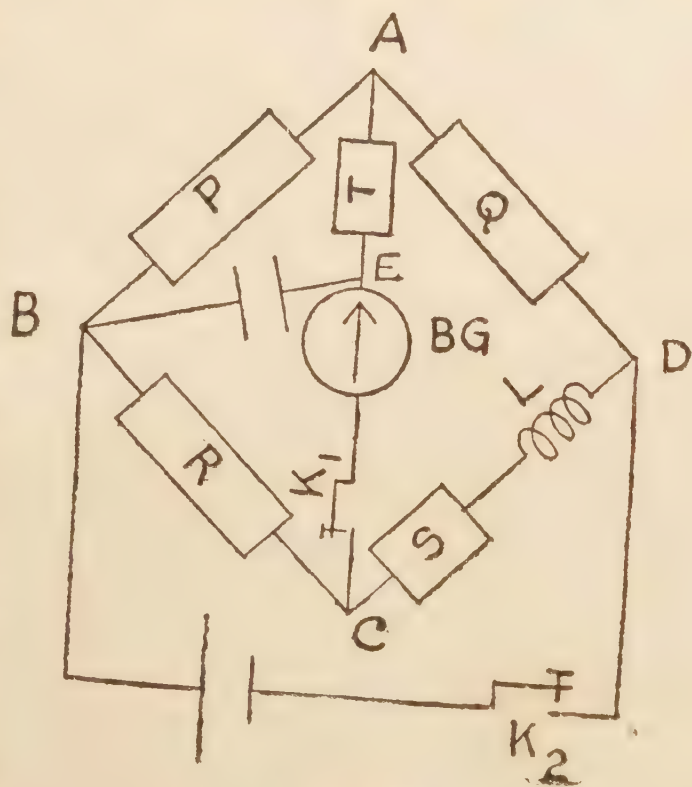


Fig. 222

If P, Q, R, S, T are the resistances unplugged in the respective boxes, C is the capacity of the condenser in micro-farads, and L the coefficient of self-induction in Henrys, then

$$L = C \{ RQ + T(R + S) \} \text{ henrys.}$$

Tabulate the results as follows :--

Capacity of condenser = 0.333 microfarads.

Coil	P ohms	Q ohms	R ohms	S ohms	T ohms	L Henries
A	1000	100	248.6	24.86	250	0.031
B	„	„	413.9	41.39	540	0.096

EXPERIMENT 103

CONDUCTIVITY OF ELECTROLYTES KOHLRAUSCH'S METHOD

Aim :—To determine the specific resistance and the specific conductivity of an electrolyte by Kohlrausch's method.

Apparatus required :—Metre bridge, resistance box of range 1 to 100 ohms, a small induction coil, two accumulators, a pair of low resistance head-phones, long glass tube, copper sulphate solution, rheostat, plug key.

Procedure :—When a direct current is passed through an electrolyte, it produces (1) a back E.M.F. and (2) a change in the concentration of the electrolyte. As a consequence, its resistance will be continuously changing. So, in place of the ordinary Lechlanche's cell or accumulator, an induction coil is used, for supplying an alternating current. In place of the galvanometer, a pair of head-phones is used for detecting the current.

The glass tube for keeping the electrolyte is about 2 to 3 cms. in diameter and is about 30 cms. long. It is mounted vertically.

It is closed at the bottom by a rubber stopper through which a thick copper-wire is passed. It carries a circular copper disc, of almost the same cross-section as the tube, at its end. The copper disc serves as one of the electrodes. The tube is closed at the top also by a rubber stopper, through which a similar wire with a disc is passed. This disc serves as the other electrode. The upper wire can be moved up and down and the distance between the electrodes altered. Copper sulphate solution is poured into the tube with the two discs immersed in it. The distance between the discs can be measured by keeping a half-metre scale behind the tube.

The two electrodes are connected in one of the gaps of the metre bridge. The resistance box is connected in the other

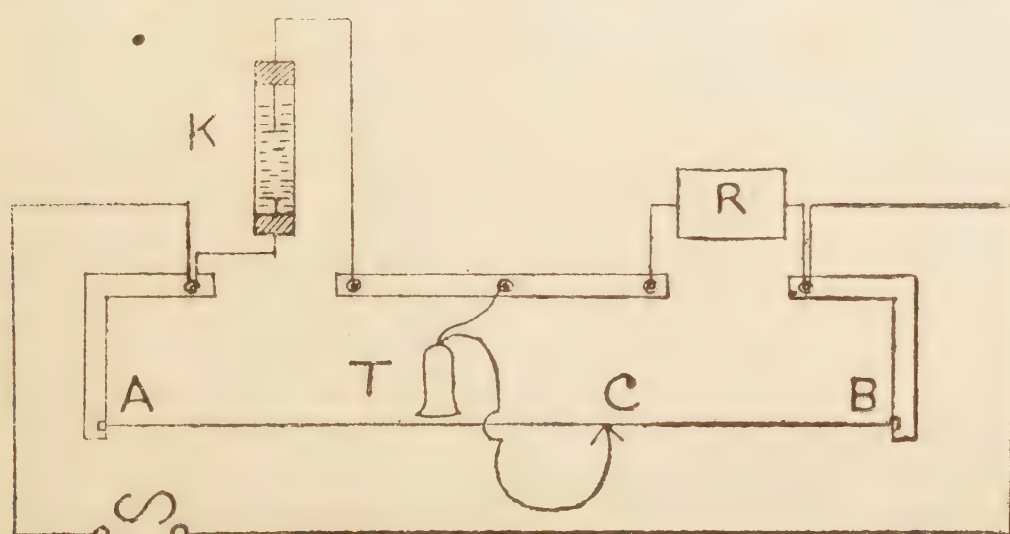


Fig. 223

gap. The primary of the induction coil is connected in series with the two accumulators, a rheostat and a plug key. The terminals of the secondary are connected to the ends of the bridge-wire.

The head-phones are connected to the contact maker on the bridge-wire and the terminal on the copper strip between the two gaps.

- Keep the two discs in the electrolyte at a distance of about 5 cms. from each other. Close the primary circuit of the induction coil. • Adjust the rheostat, so that the vibrations are neither violent nor feeble.

Unplug some resistances in the box. Keeping the head-phones close to the ear, adjust the position of the contact maker on the wire, so that the sound is minimum. It may not be possible to get complete silence, if an induction coil is used. Measure the distances of the balance point from the ends. Let them be l_1 and $(100-l_1)$. The balance point must be about the middle of the wire. Interchange the electrolyte and the resistance box. Find the balance point. Measure the distances of the balance points from the ends. Let them be l_2 and $(100-l_2)$. Find the mean of l_1 and $(100-l_2)$, and the mean of l_2 and $(100-l_1)$. Let them be l' and l'' respectively. Then, if X is the resistance of the electrolyte and R the resistance in the box,

$$\frac{X}{R} = \frac{l'}{l''}$$

$$\therefore X = \frac{R \times l'}{l''}$$

Increase the distance between the electrodes to 10 cms., 15 cms., 20 cms., etc. Repeat the experiment and determine the resistance in each case.

Find the cross-section of the tube as follows. Pour out the solution and mount the tube below a burette containing water. Draw a definite volume (V ccs.) of water into the tube from the burette. Measure the length (l cms.) occupied by the water. Then the area of cross-section X is $\frac{V}{l}$ sq. cms.

Let the resistances of the electrolyte, when the distances between the discs are L_1 cms. and L_2 cms., be X_1 and X_2 ohms respectively. Let the specific resistance be ρ . Then,

$$\begin{aligned} \text{Specific resistance } \rho &= \frac{X_1 \times a}{L_1} = \frac{X_2 \times a}{L_2} \\ &= \frac{(X_2 - X_1) \times a}{(L_2 - L_1)} \text{ ohms. per cm. cube.} \end{aligned}$$

$$\text{and specific conductivity } k = \frac{1}{\rho}.$$

Tabulate the results as follows :—

Area of cross-section of tube = a sq. cms.

Concentration of solution = gms. per cc.

Distance between electrodes cms.	Resistance in box R ohms	Balancing lengths						$X = \frac{R \times l'}{l''}$	$P = \frac{(X_n - X_1)}{(L_n - L_1)} \times \alpha$
		l_1	$(100 - l_2)$	Mean l'	$(100 - l_1)$	l_2	Mean l''		
L_1								X_1	
L_2								X_2	
L_3								X_3	$\frac{(X_3 - X_1)}{(L_3 - L_1)} \times \alpha$
L_4								X_4	$\frac{(X_4 - X_2)}{(L_4 - L_2)} \times \alpha$
Mean									

$\therefore$ Mean specific resistance = ohms per cm. cube.

$\therefore$ Mean specific conductivity = mhos per cm. cube.

EXPERIMENT 104

HYSTERESIS

MAGNETOMETER METHOD

Aim :—To subject an iron rod to a cycle of magnetisation and draw the hysteresis curve for the rod.

Apparatus required :—Long solenoid, thin iron rod, three or four accumulators, two or three rheostats, ammeter, commutator, compensating coil, deflection magnetometer, plug key.

Procedure :—Connect the accumulators in series with a plug key, the ammeter, three rheostats and, through a commutator, with the solenoid and the compensating coil.

Set up the solenoid vertically on the table. In a line with its lower end and due *east* or *west* of it, place the deflection magnetometer. Place the compensating coil along the *east* to *west* line passing through the centre of the magnetic needle, with the centre of the coil on the line. Rotate the deflection magnetometer, so that the aluminium pointer reads zero, zero.

Keep the rheostats well away from the magnetometer.

Start with the maximum resistance in the rheostats. Close the circuit. The solenoid and the compensating coil will each

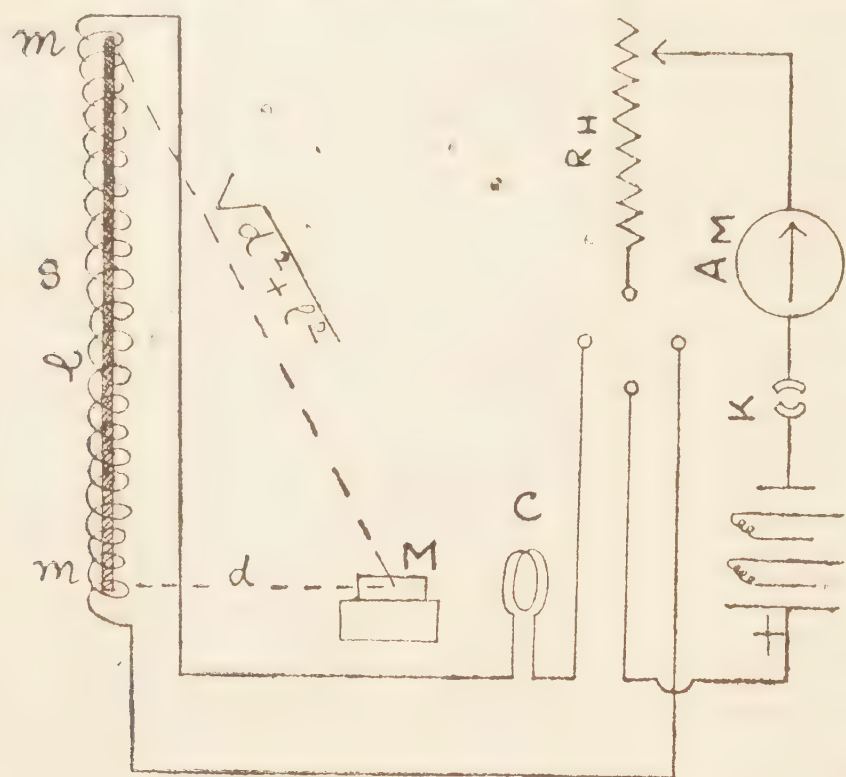


Fig. 224

produce deflections in the magnetometer. Adjust the direction of the current in them such that these deflections are opposite. Move the compensating coil to and fro, till there is nil deflection in the magnetometer. Increase the current in the circuit to the maximum safe value by altering the resis-

tance in the rheostat. Whatever be the current, the magnetometer must show nil deflection.

Introduce the iron rod into the solenoid. Its length must be slightly less than that of the solenoid. Keep it centrally inside the solenoid.

Perform a preliminary experiment. Start with the maximum current. The maximum current must be such that the deflection in the magnetometer is about 60° . Gradually reduce it to the minimum. Remove the plug, thus reducing the current to zero. Reverse the commutator, thus reversing the current in the solenoid and coil. Insert the plug in the plug key. Gradually reduce the resistance and increase the current to the maximum. Then increase the resistance gradually and reduce the current to the minimum. Remove the plug. Reverse the commutator. Re-insert the plug and increase the current to the maximum value.

Repeat this cycle three or four times—starting with the maximum current, reducing it gradually to zero, reversing the commutator, increasing the current to the maximum, reducing it to zero,

reversing the commutator and increasing the current again to the maximum.

Remove the plug from the plug key. Adjust the deflection magnetometer, so that the aluminium pointer reads zero, zero. Re-insert the plug in the key and close the circuit. Note the deflections at both ends of the aluminium pointer.

Reduce the current in steps of 0.2 amps. Note the deflections for each current. To get zero current, remove the plug. The magnetometer will show deflection, even if the current is zero. Note it.

Reverse the commutator and re-insert the plug. Note the deflections. Increase the current in steps of 0.2 amps, till the maximum current is reached. Note the deflections for each current.

Reduce the current again in steps of 0.2 amps. Remove the plug to get zero current. Reverse the commutator and re-insert the plug. Increase the current again by steps 0.2 amps. till the maximum current is reached. For each current, note the deflections at both ends of the pointer.

It is absolutely essential that the change of current must be continuously in the same direction, when it is being increased or reduced. On no account must the direction of the change of current be altered or the circuit broken, except when the current has to be reduced to zero.

Calculations :—The lower end of the iron rod is level with the magnetic needle of the magnetometer. When the rod is magnetised, a pole is induced at the lower end and an opposite pole, at the upper end.

Let the length of the magnet be l . Let the distance of the lower end of rod from the centre of the magnetic needle be, d . Let m be the strength of the pole induced in the rod. Then, .

$$\left. \begin{array}{l} \text{Intensity at centre of magnetic needle} \\ \text{due to pole at lower end} \end{array} \right\} = \frac{m}{d^2}$$

$$\left. \begin{array}{l} \text{The component of the intensity along} \\ \text{the horizontal at the centre of the} \\ \text{needle due to pole at upper end} \end{array} \right\} = \frac{m}{(d^2 + l^2)} \times \frac{d}{(d^2 + l^2)^{1/2}} \\ = \frac{md}{(d^2 + l^2)^{3/2}}$$

These two are opposite. So, the resultant intensity F is given by,

$$F = \frac{m}{d^2} - \frac{md}{(d^2 + l^2)^{3/2}}$$

$$= md \left\{ \frac{1}{d^3} - \frac{1}{(d^2 + l^2)^{3/2}} \right\}$$

If the iron rod is due east or west of the magnetic needle, the deflection θ produced is such that,

$$F = H_E \tan \theta$$

where H_E is the horizontal component of the earth's field.

$$\therefore H_E \tan \theta = md \left\{ \frac{1}{d^3} - \frac{1}{(d^2 + l^2)^{3/2}} \right\}$$

$$\therefore m = \frac{H_E \tan \theta}{d \left\{ \frac{1}{d^3} - \frac{1}{(d^2 + l^2)^{3/2}} \right\}}$$

The intensity of magnetisation I is defined as the pole strength per unit area. So, if r is the radius of the rod,

$$I = \frac{m}{\pi r^2} = \frac{H_E \tan \theta}{\pi r^2 d \left\{ \frac{1}{d^3} - \frac{1}{(d^2 + l^2)^{3/2}} \right\}}$$

If the magnetising force in the solenoid is H_S , it is given by

$$H_S = \frac{4\pi n i}{10}$$

where i is the current in the solenoid in amperes and n the number of turns of wire per cm. of the solenoid.

Again, the magnetic induction B is given by,

$$B = H_S + 4\pi I.$$

The permeability μ is given by

$$\mu = \frac{B}{H_S} = 1 + \frac{4\pi I}{H_S}.$$

Tabulate the results as follows :—

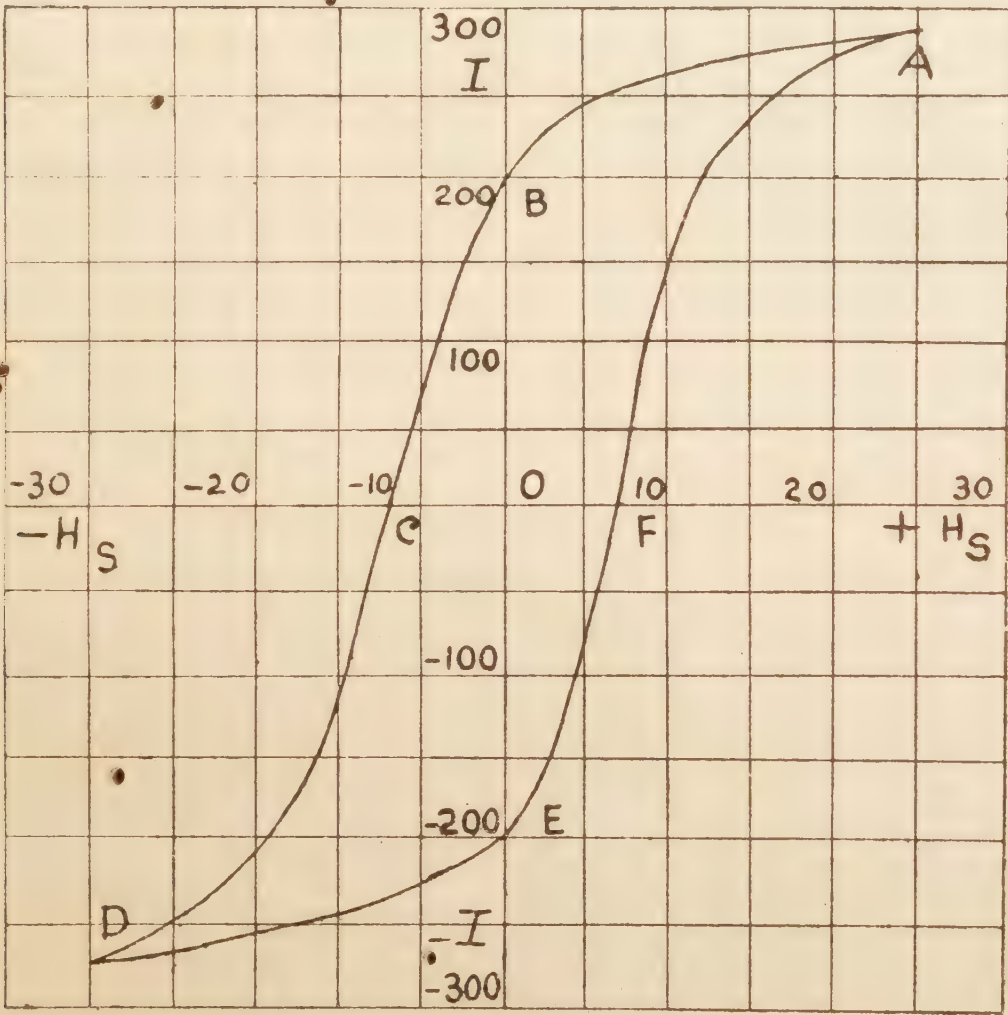
Length of iron rod = l cms.

Radius of rod = r cms.

∴ Area of cross section = πr^2 .
Horizontal component of the Earth's field H_E } = 0.38 gauss.
Distance from centre of magnetometer to lower end of rod } = d.cms.

Current in amperes i	Deflection			Tan θ	Mag- netising force H_s	Intensity of magneti- sation I	Magnetic Induction B
	θ_1	θ_2	Mean θ				

Graph :—Plot a graph representing H_s along the X axis and I or B along the Y axis. You will get a closed curve of the form ABCDEFA. It encloses a certain area depending on the specimen



I-H CURVE

Fig. 225

area. The curve is known as the “hysteresis curve.” The induction I always lags behind the magnetising force H_s . Hence, it is called hysteresis (lagging behind).

EXPERIMENT 105

CHARACTERISTICS OF A TRIODE VALVE

Aim :—To study the characteristics of a triode valve and to draw a family of curves for the same.

Apparatus required :—An L.T. (low tension) battery of 6 volts, a grid bias battery of 20 volts, an H.T. (high tension) battery of 250 volts, triode valve (6C5 or 6F5 or 6J5), mounted valve base provided with terminals, an ammeter (0 to 3 amps), a voltmeter (0 to 20 volts), a voltmeter (0 to 250 volts), a milliammeter, two large resistance rheostats, a low resistance rheostat, a commutator, three plug keys.

Description :—The triode valve has three elements inside it—a filament with its ends connected to two of the pins of the valve, a grid connected to the third pin and a plate or anode connected to the fourth pin. The grid surrounds the filament and the plate or anode is outside the grid. They are well insulated from each other.

When the filament is heated, electrons are emitted. If the plate or anode is kept at a positive potential, the electrons are attracted by it and a current of electrons flows from the filament to the plate or anode. This current can be controlled by applying a potential to the grid and altering it.

The filament voltage depends on the make of the valve. For every valve there is a maximum filament voltage rating which must not be exceeded, lest the filament should be burnt off.

For a 6C5 or 6F5 or 6J5 valve, the maximum filament voltage is 6.3 volts. They sit in octal valve bases but have only six pins. Four of them are required for the experiment.

Procedure :—Connect in series, the L.T. battery of 6 volts in series with a rheostat, an ammeter, a plug key and the two

terminals on the valve base connected to the ends of the filament.

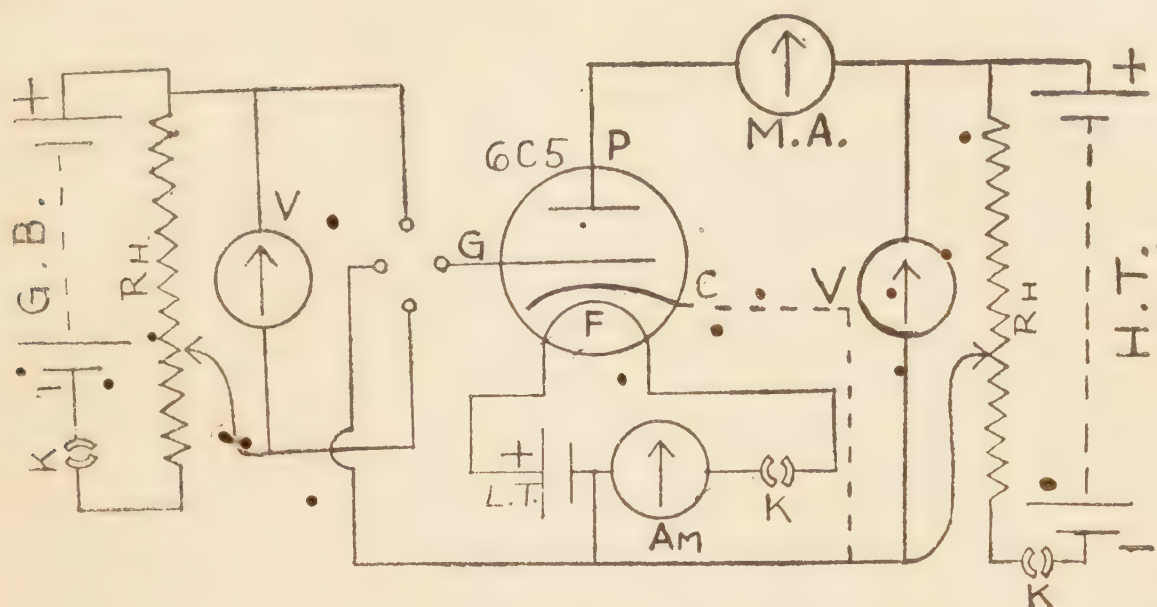


Fig. 226

Connect the grid bias battery in series with a plug key and the ends of a rheostat. Connect one of the ends of the rheostats and the sliding contact through a commutator to the grid terminal and the negative terminal of the filament L.T. battery. Connect the voltmeter of range 20 volts across the terminals of the commutator, connected to the rheostat.

Connect the H. T. battery across the ends of another rheostat with a plug key in the circuit. Connect the positive end of the rheostat, through a milli-ammeter to the plate or anode terminal P of the valve base. Connect the sliding contact of the rheostat to the negative terminal of the L. T. battery. Connect the voltmeter (250 volts) across the sliding contact of the rheostat and the terminal connected to the positive of the H. T. battery,

But, in the valves specified, 6C5, or 6F5 or 6J5, the source of electrons is *not* the filament *but* another element known as the cathode. The cathode is indirectly heated by the heated filament. So, the grid bias circuit and the H.T. negative of the plate circuit must be connected to the cathode C instead of to the negative terminal of the L.T., as shown by the dotted lines in fig. 226.

Check up the connections with the circuit diagram.

Relation between Grid voltage and Plate or Anode current

Close the filament circuit. Adjust the rheostat so that the filament current is the rated current for the valve (0.3 amps for 6 C 5 or 6 F 5 or 6J5).

Close the grid bias circuit. Adjust the rheostat, so that the voltmeter reads 20 volts. Keep the commutator in such a position that a negative potential is applied to the grid.

Close the H. T. circuit. Adjust the rheostat, so that the voltmeter reads 150 volts. Note the reading in the milli-ammeter. It may be zero, since the negative grid potential is large.

Keeping the plate or anode voltage at 150 volts, alter the grid voltage to $-18, -16, -14$, etc. till 0 is reached. Reverse the commutator and increase the voltage to 2, 4, 6, 8, etc. till 20 volts are reached. For each value of the grid voltage, read the milli-ammeter and note the current. The plate or anode voltage must be adjusted every time to read 150 volts.

Alter the plate or anode voltage to 175, 200, 225 and 250 volts. For each of these plate potentials, alter the grid potential from -20 to $+20$ volts in steps of 2 volts at a time and read the corresponding plate or anode current.

Tabulate the readings as follows :—

Plate or Anode voltage = 150 volts.

Grid voltage	20	18	16	14	12	10	8	6	4	2	0	2	4	6	8	10	12	14	16	18	20
Plate or Anode current																					
Plate or Anode voltage = 175 volts.																					
Plate or Anode current																					

Have similar tabular forms for plate or anode voltages of 200, 225, 250 volts.

Graph :—Represent grid voltages along the X axis and the plate or anode currents along the Y axis and draw the

curve for each of the plate voltages. You will get a family of curves as in the figure.

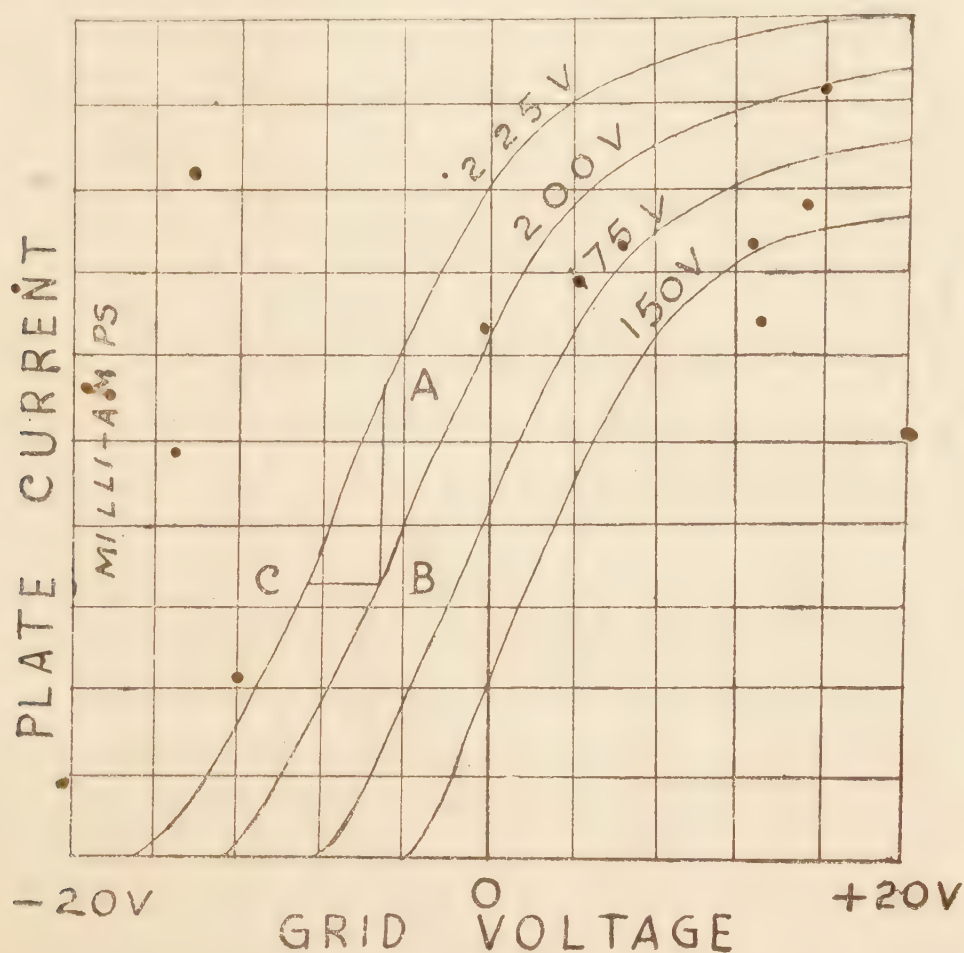


Fig. 227

Relation between Plate voltage and Plate current.

Adjust the grid potential for 12 volts. Apply the negative voltage to the grid.

Increase the plate or anode voltages from 0 to 250 volts in steps of 20 volts. Note the plate or anode current in each case.

Alter the grid potential to -10 , -8 , -6 , -4 , -2 , 0 , $+2$, $+4$, etc. For each of these, increase the plate or anode voltage from 0 to 250 volts in steps of 20 volts. Note the plate or anode current in each case.

Tabulate the readings as follows :—

Grid voltage = -12 volts.

Plate or Anode voltage	0	20	40	60	80	100	120	140	160	180	200	220	250
Plate or Anode current													

Have similar tabular forms for the other sets of readings.

Graph :—Represent plate or anode voltage along the X axis

and plate or anode current along the Y axis. For each grid voltage, you will get a curve. There will thus be a family of curves as in the figure.

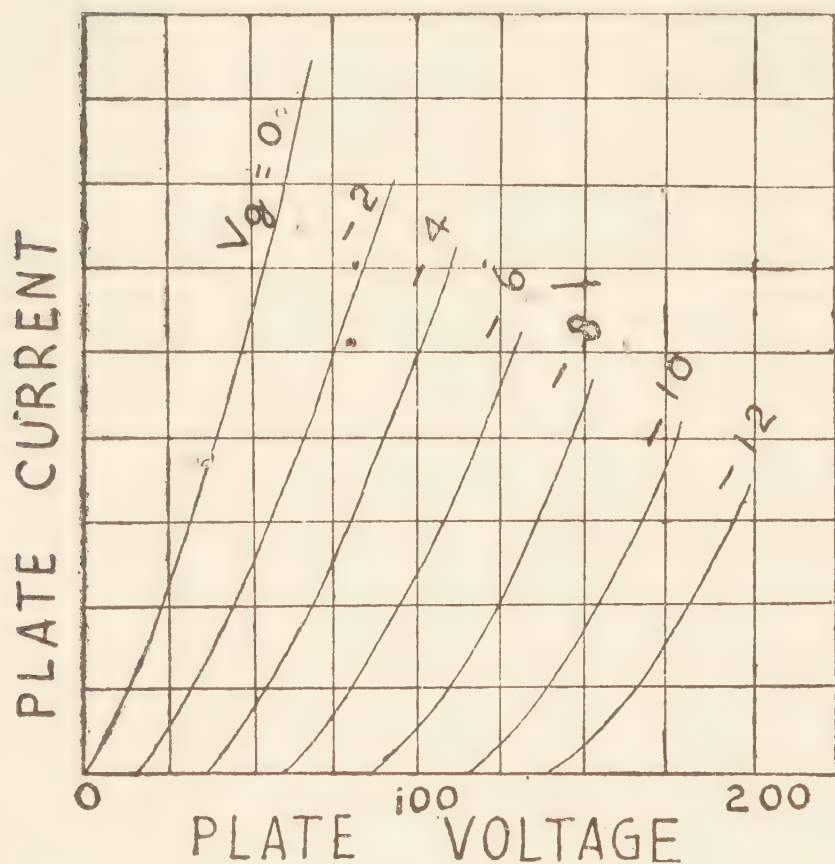


Fig. 228

The characteristics of a triode valve are (1) amplification factor, (2) plate resistance or impedance, (3) mutual conductance or transconductance.

Amplification factor or μ :—is the ratio between the change

in anode potential (dV_A) to the change in grid potential (dV_g) for constant anode current. Thus, an increase in anode voltage increases the anode current. This can be brought back to its original value by making the grid potential more negative. Thus, if the anode voltage is increased by 1 volt and the grid voltage made more negative by 0.1 volt for the anode current to remain the same, the amplification factor is $\frac{1.0}{0.1}$ or 10. It is $\frac{dV_A}{dV_g}$ for constant anode current. In graph in the figure 227, it is represented by $\frac{AB}{BC}$. From the graph, calculate the amplification factor for different ranges.

Plate resistance or impedance :—It is the ratio between a change in plate voltage (dV_A) and the corresponding change in plate current (di) and is expressed in ohms. It is $\frac{dV_A}{di}$.

Mutual conductance :—It is the ratio between a small change in plate current (di) and the small change in grid voltage (dV_g)

producing it, other voltages remaining the same. It is the ratio between the amplification factor and the plate resistance or $\left(\frac{dV_A}{dV_g} \div \frac{dV_A}{di} \right)$ or $\left(\frac{di}{dV_g} \right)$. Calculate these characteristics from your observations.

Note :—There are different types of triode valves, operated by battery or A.C. mains. The maximum voltages for the filament and for the anode are different. So, depending on the valve used, the particular voltage supply required has to be chosen.

When a voltage of 150 and above is used, you are likely to get shocks if you touch any metallic portion. Though they may not be dangerous, they are sufficient to cause annoyance. So, while manipulating the H.T. side, be careful not to touch the metallic portions in them.

APPENDIX I

QUESTIONS FOR PRACTICAL EXAMINATIONS

PAPER I

1. GENERAL PHYSICS

1. Determine the surface tension of water and of the mixtures of water and the given liquid, containing 20% and 40% of the liquid by volume, by capillary rise. Two uniform capillary tubes are given. Radius by microscope. (methylated spirit; Hares apparatus).

2. Determine the co-efficient of viscosity of the given liquid by Poiseulles flow. Use the two capillary tubes given. Measure their radii by mercury thread. (Hares apparatus ; aspirator ; sugar solution.)

3. Verify the relation between the pressure-head and the volume of liquid flowing per second through the capillary tube. Measure the radius of the tube by mercury thread. Use two tubes of the same radii but of different lengths. Calculate the co-efficient of viscosity of the liquid. (ungraduated burette ; Hare's apparatus, sugar solution.)

4. Determine the radius of the capillary tube, by measuring the rise of water in it, assuming the surface tension of water at laboratory temperature to be 70 dynes per cm. Use the same tube and determine the coefficient of viscosity of the liquid by Poiseulles flow. (burette ; sugar solution ; Hare's apparatus ; capillary tube of suitable bore.)

5. Find the periods of oscillation of the compound pendulum about various points of suspension on both sides of the centre of gravity. Draw a graph. Use it to (1) to determine the radius of gyration of the pendulum about the centre of gravity and (2) to calculate "g". Take at least three values of the equivalent simple pendulum for calculation of "g".

6. Using a pin and microscope, measure the depression at the free end of a cantilever when a load is applied at that end. Verify the relation between the load and depression produced. Draw a load-depression graph. Use it to find the weight of an unknown load. Calculate the Young's modulus of the beam. Take readings for two different lengths of the cantilever (8 to 10 slotted weights ; unknown load.)

7. Using a pin and microscope, measure the depression at the centre of a beam loaded at the centre and subjected to non-uniform bending. Verify the relation between the load and depression. Draw the load-depression graph. Use it to find the weight of an unknown load. Calculate the Young's modulus of the beam. Take readings for two different lengths between the knife-edges (8 to 10 slotted weights ; unknown load).

8. Using an optic lever, telescope, and scale, measure the depressions at the centre of a beam, loaded at the centre and subjected to non-uniform bending. Draw the load-depression graph and use it to find the weight of an unknown load. Calculate the Young's modulus of the beam (8 to 10 slotted weights ; unknown load).

9. Using a pin and microscope, measure the elevations at the centre of a beam subjected to uniform bending. Verify the relation between the load and central elevation. Draw the load-elevation graph. Take readings for two different distances between the supports. Calculate the Young's modulus of the beam (8 to 10 slotted weights.)

10. Using a pin and microscope, measure the depression at the centre of a beam, loaded at the centre of a beam and subjected to non-uniform bending. Use a constant load at the centre and verify the relation between the length between the supports and the depression at the centre. Draw a suitable length-depression graph. Calculate the Young's modulus of the beam. Take readings for two constant loads. (Metre scale ; two constant loads.)

11. Using an optic lever, telescope and scale, measure the depression at the centre of a beam loaded at the centre. Verify

the relation between the length between the supports and the depression at the centre for a constant load. Use two different constant loads. Draw a suitable length-depression graph. Calculate the Young's modulus of the beam. (metre scale ; suitable constant loads).

12. Using a pin and microscope, measure the elevation at the centre of a beam subjected to uniform bending. Use a constant load and verify the relation between the length between the supports and the central elevation. Draw a suitable length-elevation graph. Use two different constant loads and calculate the Young's modulus of the beam. (metre scale ; two constant loads).

13. Using an optic lever, telescope and scale, measure the elevation at the centre of a beam subjected to uniform bending. Use a constant load and verify the relation between the elevation at the centre and the distance between the supports. Draw a suitable length-elevation graph. Use two constant loads and take readings. Calculate the Young's modulus. (metre scale ; constant loads.)

14. Using a pin and microscope, measure the depression at the end of a cantilever when a load is applied there. Verify the relation between the length of the cantilever and the depression for a constant load. Calculate the Young's modulus. Use two different constant loads and take readings. Draw a suitable length-depression graph.

15. Using an optic lever, telescope and scale, measure the elevations at the centre of a beam, subjected to uniform bending. Verify the relation between the load and the central elevation. Use it to find the weight of two equal, unknown loads. Draw a load-elevation graph. Calculate the Young's modulus of the beam (8 to 10 slotted weights ; two equal unknown loads.)

16. Using a mirror attached to the rod in the Static Torsion apparatus, telescope and scale, measure the angles of twist of the rod for various loads. Verify the relation between the load and angle of twist. Draw the load-twist graph. Use it to find the weight of the unknown load. Calculate the modulus of rigidity of the rod (8 to 10 slotted weights ; unknown load ; vernier calipers ; screw gauge.)

17. Verify the relation between the length of the suspension wire and the period of torsional oscillations. Draw a suitable length-period of oscillation graph. Calculate the modulus of rigidity of the wire. Take readings with two wires of different radii (same material). (brass or steel wire ; screw gauge.)

18. Determine the moment of inertia of the disc by torsional oscillations, using two equal, symmetrical masses. Calculate the modulus of rigidity of the suspension wire. Take readings for two different lengths of wire. (screw gauge.)

2. HEAT

19. Find the weight of the solid in air. Suspend it in the liquid at the room temperature t , and at 50° , 60° and 70° centigrade and find its weight. Calculate the coefficient of apparent expansion of the liquid for the ranges— t to 60° and 50° to 70° . (refined oil ; large glass stopper.)

20. Find the saturation pressure of the liquid in the jolly's bulb at 40° , 45° , 50° , 55° , 60° , 65° and 70° centigrade. The saturation pressure of the liquid at 33° is 38.05 m.m. of mercury. (water.)

21. Determine the specific heat of the solid by the method of mixtures. Apply full radiation correction. (rubber stopper.)

22. Determine the specific heat of the solid kept immersed in water in the Joule's calorimeter. Ammeter and voltmeter are given. Assume the value of J . Apply full radiation correction. (aluminium foil, about 60 to 70 grams.)

23. Determine the latent heat of ice and use it to determine the specific heat of the liquid. Apply full radiation correction for the latter. (refined oil.)

24. Determine the specific heat of the solid kept immersed in water by passing steam into it. Apply full radiation correction. Assume the latent heat of steam. (aluminium foil, 100 grs.)

25. Determine the co-efficient of thermal conductivity of the bad conductor by the Lee's disc method. (new thin cardboard.)

26. Determine the emissivities of the surface at 80, 70, 60, and 50 degrees C, when it is (1) polished and (2) blackened. Calculate also the emissive power, assuming that of the black surface to be unity.

27. Determine the specific heat of the liquid by the method of mixtures. Apply radiation correction. Assume the specific heat of the solid (aluminium foil). Take two readings.

28. Draw the cooling curve of the substance for the range 95 to 70 degrees and find the melting point of the substance from the graph. Draw the cooling curve of water for the same range and determine the specific heat of the liquid. (50 to 60 grams of fresh naphthalene ; two identical wide-mouthed test tubes.)

3. SOUND

29. Determine the velocity of sound in dry air at 0°C with the resonance apparatus and use it to find the velocity of sound in the rod of the Kundt's Tube apparatus. Two tuning forks are given.

30. Verify the relation between the length of the vibrating segment of the sonometer wire and its tension. Draw a suitable graph and use it to find the weight of an unknown load. Calculate the frequencies of the two forks given. (steel wire ; suitable weights.)

31. Determine the frequency of the tuning fork with the sonometer. Take readings for six tensions. Verify by using the falling plate apparatus. (sample wire.)

32. Verify the relation between the length of the vibrating segment in the Melde's apparatus and the tension. Draw a suitable l and T graph. Use it to find the weight of an unknown load. Calculate the frequency of the tuning fork. Use both modes of vibration. (weight box ; unknown load ; sample string.)

33. Measure the length of the vibrating segment of the Melde's string, when the given solid suspended from its end is (1) in air, (2) immersed in water and (3) immersed in the liquid. Calculate the specific gravity of the solid and the liquid. Use both modes of vibration. (suitable glass stopper ; kerosene oil.)

34. Measure the length of the vibrating segment of the sonometer wire when the load at its end is (1) in air and (2) immersed in water. Calculate the specific gravity of the solid. Use two wires of different radii in the sonometer. (suitable load of cast iron or any other metal ; three tuning forks.)

35. Determine the velocity of sound in the rod of the Kundt's tube apparatus, assuming the velocity of sound in air at 0°C to be 330 meters per second. Calculate also (1) the frequency of the note emitted and (2) Young's modulus of the material of the rod. (sample rod ; vernier calipers.)

36. Determine the frequency of the tuning fork with the sonometer. Take readings for six tensions. Use the value to determine the velocity of sound in dry air at 0°C , using the resonance apparatus. (sample wire.)

PAPER II

4. LIGHT

1. Find the focal length of the convex lens by measuring (1) u and v and (2) l and D . Determine the radii of curvature of the surfaces by Boys' method and calculate the refractive index. Use the parallax method.

2. Find the focal length of the given concave lens, using a suitable auxiliary convex lens (1) in contact with it and (2) at a distance from it. Determine the radii of curvature of its surfaces and calculate its refractive index. Use the parallax method.

3. Find the focal length of the concave lens, using an auxiliary (1) convex lens and (2) concave mirror. Determine the radii of curvature of its surfaces and calculate the refractive index of the lens. Use the parallax method.

4. Using the given convex lens, form liquid lenses and determine the refractive indices of the (1) water, (2) liquid and (3) liquid-water mixture containing 25%, 50% and 75% of the liquid by volume. Draw the concentration-refractive index graph. (glycerine, convex lens of refractive index above 1.5 ; mercury float.)

5. Find the focal length of the long focus convex lens by combining it with a suitable short focus convex lens and keeping them (1) in contact and (2) at a distance from each other. Use the parallax method. Measure the radii of curvature of its surfaces with the spherometer and calculate the refractive index. (f one metre.)

6. Find the radii of curvature of the surfaces of the convex lens by Newton's rings method. Measure its focal length and calculate the refractive index. Wave-length of sodium light is 5893 Å.

7. Form Newton's rings with the convex lens and determine the wave-length of sodium light. Measure the radii of curvature of the surfaces of the lens by Boys' method. Use both faces of the lens. (mercury float).

8. Measure the angle of the prism and the angle of minimum deviation with the spectrometer and calculate the refractive index. Find experimentally the angles of incidence and emergence at angles of deviation of 1 and 3 degrees more than the minimum.

9. With the spectrometer, measure the angles of deviation of the emergent ray for angles of incidence of 35, 40, 45, 50, 55, 60 and 65 degrees and draw the $i-d$ curve for the prism. Use the curve and find the angle of the prism and the angle of minimum deviation. Calculate the refractive index of the prism.

10. With the spectrometer, measure the angles of emergence corresponding to angles of incidence of 35, 40, 45, 50, 55, 60 and 65 degrees and draw the $i-i'$ curve for the prism; use the curve to find the angle of incidence in the position of minimum deviation. Measure the angle of the prism and calculate the refractive index.

11. With the spectrometer find (1) the angle of the small angled prism, (2) the angle of deviation for normal incidence at the first face, (3) the angle of incidence at the first face when the ray emerges normally from the second face and (4) the angle of minimum deviation. Use the readings to calculate the refractive index of the prism.

12. Assuming the wave-length of the green line of the mercury spectrum to be 5461 Å, find the constant of the grating with the

spectrometer. Use it to determine the wave-lengths of the yellow, blue and the violet line in the Hg. spectrum and D_1 , D_2 lines of the sodium spectrum.

13. Determine the constant of the grating using the spectrometer and the D_1 , D_2 lines of sodium, 5890 and 5896A. Use the value and determine the wave-lengths of the yellow, green, blue and violet lines of the Hg. spectrum.

14. With the spectrometer, determine the refractive indices of the prism for the yellow, green, blue and violet lines of the Hg. mercury spectrum. Measure their wave-lengths with the grating and draw the wave-length—refractive index graph for the prism.

5. MAGNETISM

15. With the deflection and vibration magnetometers, determine (1) the magnetic moment of the given magnet, (2) its intensity of magnetisation and (3) H . Use both the Tan A and Tan B positions. Take three readings for each position.

16. Keeping the given short magnet in the vertical position with one of its poles level with the needle of the deflection magnetometer, find the average value of m/H . Find its period of oscillation in the earth's field and calculate (1) the pole-strength of the magnet, (2) its intensity of magnetisation and (3) H .

17. Compare the magnetic moments of the two magnets of unequal lengths with the deflection magnetometer by (1) the equal distance method and (2) the null method. Use both the Tan A and Tan B positions. Take two readings for each position.

18. Compare the magnetic moments of the two magnets of unequal length with the deflection magnetometer by the equal distance method, using both Tan A and Tan B positions. Verify the result by the null method keeping one of the magnets in the Tan A position and the other in the Tan B position. Take two readings for each position.

19. Mount the given magnet vertically, with one of its poles level with the needle of the vibration magnetometer and find the

periods of oscillation for various distances of the magnet from the needle along the magnetic meridian. Find the periods in the earth's field alone and calculate m and H . (Magnet of moment over 2000).

6. ELECTRICITY

20. Connect the tangent Galvanometer in series with a battery, a rheostat and a copper voltameter, and adjust the current for a suitable deflection. Annul it with the bar magnet. Calculate the current and determine the magnetic moment of the magnet and H . E.C.E. of copper 0.0003293 gm./coulomb. (10 turn coil).

21. Connect the circular coil in series with a battery, a rheostat and a copper voltameter. Adjust the current so as to get a suitable deflection in the compass box, placed on the axis of the coil (not at the centre). Annul the deflection with the magnet. Calculate the current and determine the magnetic moment M and H . E.C.E. of copper is 0.0003293 gm. per coulomb. (10 turn coil.)

22. Pass current of 0.8, 1.2 and 1.5 amperes through the circular coil and adjust the compass box along the axis of the coil for a deflection of 45 to 50 degrees. Measure the distances from the centre of the coil. Annul the deflections in each case with a magnet. Calculate its magnetic moment M and H . Ammeter given.

23. Find the resistances of the given coil of wire at the room temperature, at 0° centigrade and at the temperature of boiling water with the Carey-Foster bridge and calculate the temperature co-efficient of resistance. Draw the temperature-resistance graph. Resistance box is given.

24. Find the resistances of the two coils of wire of the same material with the Carey-Foster bridge and calculate the specific resistance. Find the length of wire of the same material in the third coil without unwinding it. Resistance box is given. (Eureka wires of three different gauges ; screw gauge.)

25. Find the resistance of the mercury thread in the capillary tube with the Carey-Foster bridge and calculate the specific

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